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HYDROMECHANICS

SHIPBOARD VIBRATION RESEARCH IN THE U. S. A.

AERODYNAMICS



by

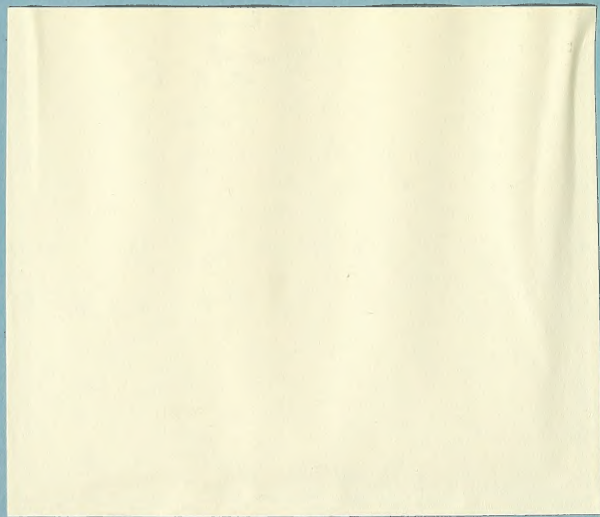
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by

Edward F. Noonan
Member of Vibration Committee

A. Report to the Vibration Committee (9)
of the
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by

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ABSTRACT

A brief review of the Hull Vibration Program at the David Taylor Model Basin and of the HS-2-1 Task Group of the HS-2 Panel (Dynamic Loadings and Responses) of The Society of Naval Architects and Marine Engineers is given. A bibliography of selected reports and papers on ship and machinery vibration is included.

Of particular note is the "Code for Shipboard Hull Vibration Measurements." This code is intended for use in the evaluation of commercial type ships and has received the approval of the Hull Structure Committee of SNAME. It has been published by The Society of Naval Architects and Marine Engineers as Technical and Research Bulletin No. 2-10. This publication was used as the basis of discussions on the subject of standard vibration measuring systems and procedures for shipboard hull vibration measurements, at the 2nd International Ship Structures Congress, held at Delft, the Netherlands, July 1964.

INTRODUCTION

A review of the work in the field of shipboard vibration in the United States will largely consist of a review of the work of the David Taylor Model Basin and that sponsored by The Society of Naval Architects and Marine Engineers. Although limited studies on hull and machinery vibration have been carried out in other naval facilities and commercial activities, they generally could be classified as the investigation of specific vibration problems, rather than research and development studies. This report makes no attempt to cover the commercial efforts, which, up to this time, have been largely proprietary in nature.

Within the David Taylor Model Basin we have five distinct Laboratories: Hydromechanics, Aerodynamics, Structural Mechanics, Applied Mathematics, and the recently formed Acoustics and Vibration Laboratory. The study of ship vibration has many facets which include the study of hull response to steady-state (propeller or machinery excited) and transient excitation which includes slamming or impulsive loadings applied by underwater explosion. Various aspects of ship vibration may be found in all five laboratories. However, since this committee is primarily concerned with steady-state vibration, I will briefly review the Hull Vibration Program of the Vibration Division of the Acoustics and Vibration Laboratory (formerly the Ship Dynamics Division of the Structural Mechanics Laboratory). Additional work of interest to this committee, in the study of propeller-excited hydrodynamic forces, will be covered by Dr. John Breslin.

The study of the response of ship structures to the various exciting forces imposed on it during normal operation constitutes a major field of interest at the Model Basin. The objectives of the Laboratory in this area are concerned with:

1. Mechanical Suitability (strength adequacy)
2. Habitability and Operability (effects on performance)
3. Detection and Detectability (underwater noise)

It immediately becomes obvious from the complexity of the mass-elastic system, the various types of exciting forces, and the alternate objectives of the program that this field of study becomes too broad to handle as a single project. Consequently the total program at DTMB has been broken down into a number of smaller programs which may be identified as:

1. Hull Vibration (Response to Steady-State Forces)
2. Structural Seaworthiness (Hull Response to Heavy Seas)
3. Slamming (Ship Response to Wave Impact)
4. Hydroelasticity (Flutter Prediction)
5. Radiation (Study of Hull Vibration for Noise)

Although many factors, analysis techniques, and fundamental theoretical concepts are common to more than one program, nevertheless, the resolution of the total program is sufficiently broad as to warrant the subdivision shown. This has also been recognized by the Ship Structure Committee of The Society of Naval Architects and Marine Engineers which has divided the HS-2 Panel (Dynamic Loadings and Responses) into three Task Groups:

1. HS-2-1 (Vibrations)
2. HS-2-2 (Surge Loadings)
3. HS-2-3 (Slamming)

The Hull Vibration Program reviewed in this presentation concerns itself with the limited field of interest, Response to Steady-State Forces, and corresponds to the interest of the Vibration Task Group of the HS-2 Panel.

In the development of the Hull Vibration Program we are primarily (although not exclusively) concerned with the second objective, Habitability and Operability. By this we mean the steady-state forces are generally of more concern for their annoyance to personnel or malfunction of equipment. In some cases damage or danger of damage to ship structures and equipment has occurred. However, most cases of structural damage have resulted from transient excitation and would be covered in either the TMB Structural Seaworthiness Program or the Slamming Program. The TMB Radiation Program concerns itself with modes of hull vibration which are of particular significance in underwater noise. This program is directed primarily to submarines and is concerned with amplitudes which are generally of no concern in regard to mechanical suitability or habitability and operability.

This report includes three parts:

Part One – TMB Hull Vibration Program, and includes the following major categories:

- I. Hull Structural Response (Primary Hull Girder)
- II. Influence of Other Ship Structures on Hull Structural Response
- III. Propeller-Excited Vibratory Forces
- IV. Experimental Studies
- V. Design Procedures and Standards

Part Two – SNAME HS-2-1 Program

- I. The “Norm” Program
- II. Long-Range Objectives
- III. Code for Shipboard Hull Vibration Measurements

Part Three – Bibliography

- I. Basic Reports
- II. Ship Structures Reports
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PART ONE

TMB Hull Vibration Program

I. HULL STRUCTURAL RESPONSE (PRIMARY HULL GIRDER)

A. DEVELOPMENT OF HULL VIBRATION THEORY IN FLEXURE AND TORSION

A comprehensive study reviewing and extending previous work was made of the derivation of equations for digital and electric-analog solution of the natural frequencies and mode shapes of a ship hull idealized as an elastic beam.

Effects of bending, shear, rotary inertia, coupled torsion and bending, initial curvature of the elastic axes, applied forces and torques, sprung masses, and other sprung inertias are included. Methods for manually calculating the physical parameters of the hull from ship plans and other sources have also been treated. The accuracy of the results obtained by these methods for uniform and nonuniform beams has also been determined. The results of this study were reported in TMB Report 1317. A more general three-dimensional approach to ship vibration is also being studied.

B. DEVELOPMENT OF COMPUTER AND MODEL TECHNIQUES

Electrical analog circuitry and digital computer codes incorporating all of the preceding effects have been devised and reported in TMB Report 1317. The analog circuitry is set up on the Structural Mechanics Laboratory Analog Computing Facility, called TMB Network Analyzer, which is described in TMB Report 1272. Extensive improvements recently made on the analyzer increase the ease and flexibility of operation as well as the speed of analysis. Control and analysis features include manual and automatic scanning of each of the 48 stations (positions) on the analyzer patch board selection so that these stations may be scanned in any desired order, instantaneous visual electronic display of the selected stations on a 17-inch scope, automatic digitizing, and print out data together with simultaneous point-by-point graphing of the data on a 17-inch scale. In addition, 10 active analog computer amplifier channels have been installed. These may be incorporated in the analyzer circuitry to simulate active systems, generate specialized forcing functions, or perform special analysis of data.

C. INFLUENCE OF SPRUNG MASS ON HULL VIBRATION THEORY

On certain classes of ships, flexibly mounted masses such as machinery, rudders, cargo, and superstructures affect hull vibrations. Therefore, to explore the possibility of a more adequate representation of a ship hull as a mass-elastic system subject to vibration, studies have been made to investigate the characteristics of a beam with attached inertias

having motion in translation, rotation, or coupled translation and rotation. Analytical, electric-analog and digital computer methods have been devised to determine the natural frequencies and mode shapes of beam-sprung-inertia systems. The results of these studies are given in TMB Reports 955, 1215, 1317, 1507, and 1540.

D. STUDY OF SIGNIFICANT PARAMETERS

To determine the normal mode frequencies and mode shapes of a particular ship it is necessary to evaluate the physical parameters of each section of the ship for use in the finite difference equations. For the general case of coupled torsion-horizontal bending vibrations, methods for manually computing these parameters from ship plans and other information have been devised and reported in TMB 1317. For steady forced vibrations, the mathematical representation of hull damping is based upon experimental results and is reported in TMB Reports 1060 and 1451. An example of its application in calculations of hull response is given in TMB Report 1384. As an alternative to using a constant value of j corresponding to the two-noded mode, a method has been developed which will allow for a different j factor for each mode and is reported in TMB Reports 1317 and 1623. The need for the development of methods which will give more accurate parameter values for the bending shear and torsional rigidities as well as the virtual mass still persists. A method which uses a digital computer to calculate the hull parameters from basic data tabulations obtained from ship plans in accordance with a preestablished systematized procedure is being devised to reduce the labor, expense, etc. of making such calculations.

II. INFLUENCE OF OTHER SHIP STRUCTURES ON HULL STRUCTURAL RESPONSE

A. MACHINERY-INDUCED VIBRATION

It is obvious that the propeller, as a machinery item, is probably the major contributor to the steady-state vibration of a ship. The TMB program on propeller-excited vibratory forces is described in Section III. This section will deal with machinery-induced vibration *except* that introduced by the ship propellers directly.

The major cyclic forces which may stimulate the ship hull are associated with the main propulsion system and result from cyclic forces which may or may not reflect conditions of resonance. These forces may be associated with excitation originating within the machinery system or with excitation corresponding with propeller blade frequencies or harmonics of it. Of course the presence of machinery resonance and the tuning of such resonance with a natural frequency of the hull may result in very severe and often damaging vibration. For convenience, we can classify machinery-induced vibration as longitudinal, rotational, or lateral.

1. Longitudinal

Although the major source of excitation of longitudinal vibration is the propeller, the response of the hull is a function of the driving forces, which may be seriously magnified by the presence, or near presence, of resonances in the machinery system. Early in World War II, very serious longitudinal vibration of the main machinery system of the latest carriers and battleships was observed. The basic solution to the machinery problem was well documented in TMB Report 1088, "Longitudinal Vibrations of Marine Propulsion Shafting Systems," by Kane and McGoldrick. This paper, which later appeared in Transactions of SNAME, did not completely satisfy the problem of hull vibration. Tests conducted on the MIDWAY-Class carriers, from 1947 through 1949, clearly demonstrated that the best that could be obtained was a compromise between the needs of the hull and the requirements of the machinery system. The use of the optimum propellers with regard to hull vibration would result in damaging machinery vibration. Conversely, the ideal propeller for the machinery system leaves much to be desired from the point of view of hull vibration.

Longitudinal vibration of the machinery system, has also been a problem in some classes of submarines. As a result, renewed emphasis is being placed on the understanding and control of longitudinal vibration of machinery systems and its influence on the response of the ship structure.

2. Rotational

a. Torsional. Torsional vibration has generally been considered as strictly a machinery problem. This is far from the truth when you encounter torsional vibration in propulsion systems with large exciting forces, as is the case with diesel engine drives. When the exciting frequencies of the machinery system coincide with hull natural frequencies, structural vibration may occur. Cases have also been encountered where engine-excited torsional criticals in the propulsion system result in high alternating thrust components as a result of the torsional alternating load exerted on the propeller. Some of these cases have been sufficiently serious as to cause failures of the main thrust bearing and serious vibration of the hull. These vibrations were of engine frequency and not propeller frequency.

The Model Basin has evaluated the torsional characteristics of proposed propulsion systems in a number of cases and contributed to the general understanding of the value of the "nodal" drive in the case of the geared turbine system. Our analog computer has been developed to handle such problems and in the future, we expect to delve more deeply into the subject.

b. Whirling. A shaft sags between two bearings. As it rotates, the stress pattern alternates. If it rotates fast enough, it is in danger of whirling, a situation which may be compared with the action of a skip-rope and one in which the fiber in tension remains in tension. This condition is likely to be destructive and obviously would transfer large unbalanced forces to the hull, through the bearings. This phenomenon was considered as possibly contributing to the relatively high incidence of shaft failures noted on commercial ships at the close of World War II.

DTMB has studied this problem and in the past has issued several valuable papers in this area, among which are TMB Report 827, "A Theoretical Approach to the Problem of Critical Whirling Speeds of Shaft-Disk Systems," and Report 890, "A Design Approach to the Problem of Critical Whirling Speeds of Shaft-Disk Systems." Both were authored by Dr. N. H. Jasper.

Although this phenomenon has not been established as a cause of the shaft failures, the understanding of the phenomenon and its importance in the development of design criteria for shafting systems should be pursued by DTMB in the future.

3. Lateral

a. Bending. Bending has been established as the major alternating load on propeller shafts and is believed to be a major influence on the shaft failure problem. The phenomenon has been adequately explained in the literature, the most recent publication being prepared by DTMB in Report 1596 by Price, et. al., on "Bending and Torsional Stresses in Propeller Shaft of USS OBSERVATION ISLAND (EAG 154) in Smooth and Rough Sea." Previous studies by DTMB included those of USS MISSION SAN LOUIS OBISPO, USS NORFOLK (DL 1), and limited studies on several submarines of the SKIPJACK class. TMB Report 947, by McGoldrick, presents "A Theorem on Bending Stresses in Rotating Shafts."

The TMB program in this area includes additional proposed full-scale studies aimed at the development of improved shaft design procedures. It should be realized, however, that all efforts to reduce the alternating bending loads on the propeller shaft, introduced by the eccentric thrust component, will in the final analysis, also serve to reduce the vibration of the hull by the reduction of the alternating forces entering through the shaft bearings.

b. Unbalance. Unbalance has long been recognized as the fundamental source of vibration in rotating machinery. DTMB has been engaged in many studies on the influence of unbalance forces in propulsion systems as a source of serious hull vibration. As explained in TMB Reports C-36 and C-414, unbalance, mass or hydrodynamic, was largely responsible for serious hull vibration in a destroyer and an aircraft carrier. Although the application of balancing tolerances of MIL-STD-167, "Mechanical Vibrations of Shipboard Equipment," has served to reduce the vibratory forces from this source, nevertheless, a

reasonable portion of our everyday difficulties may be attributed to unbalance. The plans of DTMB for the future includes further study into the understanding and control of this problem and in the development of improved specifications and standards.

This review emphasizes the importance of machinery vibration to the response of a ship hull. These same problems will also precipitate undesirable vibration of local structures under favorable circumstances. It is still an important consideration, however, that to effectuate low vibration levels in ship structures, the best approach is to understand the cause of and establish satisfactory methods for the elimination or reduction of the exciting forces.

B. INFLUENCE OF SHIP SUBSTRUCTURES

The principal structures falling in the category of ship substructures are: deckhouses, superstructures, masts, gun turrets, and missile launchers.

DTMB plans to investigate ship substructures to establish vibration levels and determine the effects of these structures on hull vibration and hull-girder strength. This investigation will include the effects of substructure configuration, method of attachment, and materials used for construction of these structures.

1. Configuration

- a. Length of substructure relative to hull length (shear stiffness effect).
- b. Location of structure in respect to nodal points of hull vibration (strain limits and mode effects).
- c. Height and width of structure.
- d. Shape of structure; i.e., superstructure decks may or may not be of uniform length.
- e. Effect of expansion joints.

2. Method of Attachment

- a. Structures rigidly attached to ship hull girder.
- b. Flexibly mounted structures.

3. Materials

- a. Steel.
- b. Alloy.
- c. Plastic.

C. INFLUENCE OF APPENDAGES

A comprehensive theoretical study has been made for determining the vibration and flutter characteristics of coupled rudder-diving plane ship vibration systems in forward motion subject to hydrodynamic forces on the rudder. Treatment of "Sprung Body Effects," which consider the influence of heavy elastically attached inertias with one or two degrees of freedom such as a nuclear reactor, machinery, cargo, superstructure, radar mast, boiler, etc. on the response of the hull-control surface system, is included.

Special emphasis is placed upon digital and electric-analog methods of solution for determining the natural frequencies, mode shapes, critical flutter speeds, and damping of this system and/or parts of this system. This study is reported in TMB Report 1507. Methods for evaluating the hydroelastic parameters for a rudder have also been developed. The procedure for computing these parameters including the damping is given in TMB Report 1508. In particular, methods for determining the structural and viscous damping values for control surfaces from measurements on such surfaces in drydock (or at sea) have been developed. A comparison of theory and experiment for marine control-surface flutter has been made for a model. The work was presented at the Fourth Symposium on Naval Hydrodynamics and is also reported in TMB Report 1567.

III. PROPELLER-EXCITED VIBRATORY FORCES

A. ANALYSIS OF STRUCTURAL AND MACHINERY RESPONSE TO CYCLIC FORCES AS DETERMINED FROM MODEL WAKE DATA

The objective of our program is to develop an adequate theory and method of calculating propeller forces, and of computing the response of the hull and machinery to these excitations. It is necessary to know the relationship between the forces generated and the response of the structure to these forces within the frequency range of interest.

The propeller forces and moments vibrating the ship hull and structures are induced by:

1. the nonuniform inflow-velocity into the propeller plane which then transmits forces to the hull through the shaft, struts, bossings, or stern bearings;
2. oscillating fluid pressures generated by the moving pressure fields associated with the blades of the loaded propeller when passing strut arms, bossings, or the hull; and
3. mechanical forces resulting from geometric imperfections of the propeller or of the rotating or reciprocating machinery members.

The following approach is necessary to understand and predict the propeller forces induced by Item 1:

- a. Conduct model wake measurements in the plane of the propeller at the corresponding displacement, trim, and speed of the ship to determine the longitudinal (wake) and tangential velocity components.
- b. Analyze the harmonic content of the circumferential wake at various radii within the propeller plane. This will permit the selection of a propeller with the optimum number of blades for minimum thrust and torque forces.
- c. Calculate thrust and torque force fluctuations as derived from the wake survey.
- d. Calculate the off-center thrust (eccentricity) in radial and angular directions.
- e. Calculate the horizontal and vertical bearing forces.

Inadequate information exists on the fluctuating pressures produced on the surface of the ship by propeller action to permit computation of the forces generated. Tests are currently planned to obtain additional information in this area. Information is also required to determine the magnitude of the forces transmitted through the bearings. Static and dynamic mass unbalance due to geometrical imperfections or lack of symmetry will excite forces and moments at shaft speeds.

It is considered important, in the design of a ship, to be able to predict the response of the primary hull girder to known exciting forces. This would permit an evaluation of the capability of the ship to perform its intended function and to provide a basis of general approval of the more important design aspects. It is obvious, however, that such a program requires the following basic ingredients before one design can be compared to another or before a design can be evaluated against a given control factor:

1. A "Basic Computer Program" (Here we are referring to a "Basic Computer Program" as a series of coded problems.) which permits the study of the response of a mechanical system;
2. A computer program which permits the rapid computation of the exciting forces;
3. A better understanding of damping mechanisms;
4. Improved knowledge of virtual mass;
5. Suitable vibration specifications or limits of acceptability for vibration of the system under study; and
6. Full-scale program of applicability studies.

B. INVESTIGATION OF FORCE CANCELLATION MEANS

The most effective way to solve the problem of hull vibration would be the cancellation of the cyclic forces acting upon the hull.

Even the reduction of the steady-state hydrodynamic forces induced by the propeller is difficult. Empirical concepts have to be developed concerning pertinent design features such as: position of the propeller in relation to the hull and rudder, clearance around the propeller, modification of the propeller rake, the skew, and the inclination of the propeller to the hull. In the future, vibratory motions resulting from the pulsating pressure fields at the stern area may well be expected to increase. This may either require a change in stern configuration or the development of force cancellation devices.

To cancel cyclic forces acting upon the hull, forces equal and opposite to the external forces must be considered in form of dynamic vibration absorbers, adjustable rotating eccentrics, and shaft synchronization devices on multiple-screw ships. In this area we are interested in receiving results of studies designed to absorb or cancel the oscillating forces in the vicinity of the propeller by replacement of plates with other flexible material.

Counter-rotating propellers may show advantages in reducing vibration. Several installations of this type are presently under study.

Practical design consideration as well as variation in operating conditions preclude the possibility of cancelling the exciting forces. These forces can be reduced but probably involve higher ship construction costs or lesser design efficiency.

IV. EXPERIMENTAL STUDIES

A. VERIFICATION OF DEVELOPED THEORIES

One of the main theories to be verified by experiments concerns the beam theory with its last advances, i.e., effect of sprung masses, appendages, and superstructures on frequencies and mode shapes. Experimentally this requires transducers and test arrangements which allow a clear definition of mode shapes and frequencies. This is accomplished by the addition and subtraction of outputs of various gages. A still more complex task is the verification of response at low hull vibration levels where the magnitude of vibration displacement may be of the order of microinches instead of millinches.

Case studies were made on USS FARRAGUT for the rudder-hull system (Flutter), NS SAVANNAH for the sprung-mass effect of the reactor compartment, on several submarines for the hull-propulsion system as a sprung mass, and on USS LONG BEACH (CG(N) 9) for the effect of tall superstructures.

B. MEASUREMENT OF PARAMETERS (SEE SECTION I)

In all vibration surveys there is still a discrepancy of several percent between calculated and experimental values of frequencies. This is probably due to some of the effects mentioned in IV.A, sprung mass, etc., but more probably due to inaccurate knowledge of certain parameters such as virtual mass of water, rigidity of the hull, and position of the center of mass in a section. Methods are under study which will permit the calculation of these parameters directly from ship data. Similar studies are also underway which allow the determination of spring constants of radar masts and similar structures. Careful planning will allow the determination of damping characteristics. In this program, the use of impulsive loadings is under study and looks promising.

C. DEVELOPMENT OF EXPERIMENTAL TECHNIQUES

1. Shakers

The evaluation of hull frequencies and mode shapes, natural frequencies of substructures like bulkheads, thrust bearing, etc., is done by use of a number of shakers available which were developed during past years. These facilities include a 40,000-lb and a 5,000-lb vibration generator for frequencies up to 30 cps, small shakers like the TMB medium vibration generator, a Lazan shaker, etc. It also includes instruments which exert a known point force and allow the measurement of the structural response at the same or any other point to obtain mode shapes, frequencies, damping, and transfer functions.

2. Measuring and Recording Systems

The measuring system was drastically changed during the recent years by replacing mechanical instruments with electrical instruments such as accelerometers, velocity meters, combination of the latter, etc., to cover frequencies in the range from zero to about 8000 cps with emphasis on the frequencies up to 50 cps. Recordings of the data are made by use of recording oscillographs and magnetic tape recorders.

3. Analysis Systems

The analysis of vibration as recorded on paper is done in the well-known fashion as described in many reports, by evaluating frequencies present and the corresponding amplitudes.

The electronic tape analysis allows a much broader and accurate evaluation by obtaining frequency-amplitude spectrum, power spectrum, average and rms amplitudes, etc. It shows all frequencies and also the amount of random vibration present. The amplitudes cover a range of nearly 40 db.

The analysis system also includes a statistical evaluation of vibration amplitudes and provides histograms, mean values, and standard deviations of certain selected frequencies.

4. Test Procedures

Test procedures are refined so that analysis of modes of vibration are possible. This also permits the separation of bending and torsion in the coupled torsion bending modes, and the separation of the three rotational and three translational vibrations, when needed. Test procedures also permit phase determinations between different locations and permit the development of relative amplitude curves.

D. METHODS OF DATA PRESENTATION

Data are presented in the form of tables which list frequencies and corresponding amplitudes. Selected frequencies are shown in the form of curves for the whole speed range. These frequencies are usually blade or shaft frequencies.

The vibratory level at a selected location may be presented in the form of amplitude spectra, and the vibration amplitude of a selected frequency may be shown in the form of an average value or maximum value.

E. DESIGN EVALUATION

Design evaluation, so far, usually covers the vibratory level of a ship class (first of the class vibration survey) and compares the results with those obtained in other classes.

An evaluation of test results usually is made to identify the source of vibration, when it is considered excessive. Remedies are suggested whenever possible.

Response characteristics of hull to unit force excitation are calculated, and experimental results are compared with calculated values to obtain the hull mobility. The same procedure is used for surface ships as well as for submarines.

Other evaluations concern the selection of locations for machinery or the necessary reduction of vibratory forces by use of vibration reducers.

F. ENVIRONMENTAL STUDIES

Environmental studies are required to determine acceptability of equipment in meeting specifications. Studies are made on radar platforms, masts, electronic mounts, crew quarters, etc.

There is no "norm" yet established which will present the vibratory environment at any given location. The approach used is described in MIL-STD-167. Generally, values of environment are presented in two ways, displacement versus frequency or acceleration versus frequency.

One approach under study considers the presentation of the vibratory environment in the form of statistical distribution functions, i.e., a mean level may be established together with a standard deviation. The latter will define the probability of the data falling within the prescribed band.

V. DESIGN PROCEDURES AND STANDARDS

The practicing naval architect has not the time to study the exponentially increasing volume of technical literature to overcome problems important for the design of a ship. Today, he must have the ability to translate the theoretical approach into practical application. Most theoretical analyses and predictions are based on ideal properties and may be inapplicable or require a correction factor. However, it is most important that the naval architect be aware of the fundamental concepts which are significant and should be considered in the earliest design stage. It is, therefore, necessary to provide him with a guide useful in the early design stages and which will permit the verification of ship response by reliable calculations at a time when design changes are possible. He should also be provided with standards, norms, and specifications useful in vibration control. Vibration characteristics are seldom considered in the preliminary design procedure, but are important to avoid later problems of mechanical suitability, habitability, and operability. Mr. McGoldrick's TMB Reports 1451 of December 1960 and 1609 of April 1962 will assist in better communication between the scientist doing research and development work and the practicing naval architect.

A. DESIGN PROCEDURES

The objective is to establish rational methods to be used during the design stage of a naval vessel to prevent vibration levels which will interfere with proper functioning of ship-board equipment. Reasonably simple methods of predicting hull and machinery response should be provided. Shaft rpm and blade frequency should be chosen to avoid hull resonances, where possible. The choice of propellers and details of hull design should be studied to obtain minimum exciting forces.

It is the objective of the Vibration Division to develop a computer process or processes which would logically fit into the design procedure. For example, it is quite logical that such a program of vibration analysis could be utilized in the early stages of preliminary design as an accepted influence on preliminary lines, machinery details, general arrangement, choice of propellers, etc. This program presumably would replace the limited vibration analyses that are now carried out, generally after the fact. It is obvious, however, that such a program required the following basic ingredients before one design can be compared to another or before a design can be evaluated against a given control factor:

1. A "Basic Computer Program" (Here we are referring to a Basic Computer Program as a series of coded problems.) which permits the study of the response of a mechanical system;

2. A computer program which permits the rapid computation of the exciting forces;
3. A better understanding of damping mechanisms;
4. Improved knowledge of virtual mass;
5. Suitable vibration specifications or limits of acceptability for vibration of the system under study; and
6. Full-scale program of applicability studies.

At this time a Basic Computer Program exists at the Model Basin and is applicable to any mechanical system, such as a ship hull or main propulsion plant. The response of a ship to simple harmonic driving forces is a function already available in the Basic Computer Program. Studies of hull mobility, when driven by a unit exciting force, is frequently carried out. Vertical bending modes, as well as other modes, are also computed regularly. The response of shafting systems, is also regularly computed. It is fair to say that a "Basic Computer Program" which permits the study of the response of a given mechanical system presently exists. A handbook on "Coded Vibration Problems" which describes the individual problems, is being prepared. Another project, "Mechanized Calculation of Ship Parameters," is essentially complete. This project is intended to simplify the determination of computer inputs for studies of hull response.

The analysis of wake patterns, necessary to the development of exciting forces, already exists. A computer program, which permits the development of wake harmonics from wake patterns, also exists. The calculation of propeller-exciting forces in various wake distributions has been developed by Pien. What remains to be done in this area, however, is the development of the process to that state of perfection which would permit the rapid determination of propeller forces in a routine manner. For example, the operation of any given propeller in a given wake pattern requires considerable detailed effort in working from the propeller drawings. Presumably, this process can be mechanized.

Further R&D effort is required. Although the factors of damping and virtual mass can be handled at the present time in the existing basic program, the constants used, particularly that of damping, are considered inadequate. A project has been initiated during the current year to develop a program on Hull Damping.

Vibration specifications, or criteria, is considered a long-range or "live" project. Our project on "Vibration Norms" is intended to serve this purpose but, even when completed, must be continually updated. In this regard, criteria or specifications for machinery vibration is much further advanced.

The full-scale program of applicability studies is also an active or "live" program. Whenever possible, full-scale studies (such as the NS SAVANNAH studies) are carried out to assist in developing our prediction techniques.

B. DEVELOPMENT OF STANDARDS

Standard measurement and analysis procedures are being developed to permit better comparison with calculations and with data obtained on other ships.

Norms of hull vibrations are being prepared to define specifications for tolerable vibration levels for various classes of surface ships and submarines. For this purpose full-scale test data on all newly constructed vessels are collected and characteristics which contribute to ship vibration are classified. Vibration norms have been already established for the following submarine classes: TANG, TANG (improved), GATO (converted), TENCH, BALAO, BALAO (converted), SKIPJACK, GEORGE WASHINGTON, and THRESHER, and for the experimental submarines: SEAWOLF, NAUTILUS, and ALBACORE. Work is continuing to complete norms for all submarines, and plans are being developed to establish norms for surface ships.

C. DEVELOPMENT OF SPECIFICATIONS

Work has been started to establish general ship specifications and to revise military standards, to determine environmental vibration levels for the more sensitive equipment being developed for installation on specific ships. Existing hull vibration data have been correlated with existing MIL-STD requirements. After receipt of vibration data on the newest nuclear ships, recommendations for revision of MIL-STD 167 will be submitted.

PART TWO

SNAME HS-2-1 Program

The S-6 Panel (Hydrostructure Vibration) was organized in August 1953 under the direction of the Hull Structure Committee of The Society of Naval Architects and Marine Engineers. Probably the best definition of the purpose and objectives of the S-6 Panel was presented in October 1960 and were as follows:

1. To investigate the response of ship structures to exciting forces and thereby develop recommendations which would lead to assured satisfactory ship vibration characteristics.
2. To recommend and support research directed toward an improved understanding of the response of ship structures to exciting forces.
3. To recommend publication of vibration design criteria and guides, through SNAME.

The program objectives of the S-6 Panel are presently being carried out under the newly formed Panel HS-2 (Dynamic Loadings and Responses). This Panel held its first meeting on 15 February 1962 at which the total interest of the Panel was assigned to three distinct Task Groups:

- | | |
|-------------------|-------------------|
| 1. Vibration | Task Group HS-2-1 |
| 2. Surge Loadings | Task Group HS-2-2 |
| 3. Slamming | Task Group HS-2-3 |

I. THE "NORM" PROGRAM

A. BACKGROUND

The vibration of ship hulls and various local structures is the result of I – Forced vibration induced by the propulsion machinery, shafts or propellers, or II – Random vibration induced by hydrodynamic forces acting on the hull during rough weather operation. Both types of vibration are of importance in the design and construction of commercial as well as naval ships.

The first type, forced (or steady-state) vibration, is generally associated with propeller blade or shaft frequencies or with the major forces in the main machinery. This forced vibration may be resonant or nonresonant and is of particular importance in determining the acceptability of the hull vibration levels under normal trial or operating conditions (sea conditions not greater than 3 as defined by the U. S. Navy Hydrographic Office Sea State Code.)

The second type, random (or transient) vibration, is generally associated with the natural frequencies of the hull or structural subassemblies excited by wave impact or pounding of the ship in heavy seas. This vibration is random in nature, is a function of sea conditions,

speed and heading of the ship and is of primary importance in the determination of the ship seaworthiness and for adequacy of the design of subassemblies such as antennas, masts, etc., under heavy weather operations.

For simplicity we may say that the "smoothness" of a ship under normal operating conditions in a State 3 sea or less, is determined by the forces generated and the structural response of the ship and is associated with forced vibration. In like manner we may say that the ship seaworthiness, or the adequacy of the design of its subassemblies, is determined by the forces generated and the structural response of the ship under the influence of heavy seas.

These two areas of vibration are distinct, the first having a criterion of comfort, and the second of stress level. The evaluation of these two types of vibration would therefore require widely different considerations in the determination of levels of acceptability. This program deals with the establishment of "Norms of Vibration for Various Classes of Ships" when stimulated by type I - Forced Vibration.

B. PURPOSE

A long term program of study, under the joint sponsorship of the H-8 and the original S-6 Panels, has as its objective the complete understanding and control of the forces and structural response of a ship as influenced by forced vibration. It is the purpose of this program to define the "Norms" of vibration, for the forced vibration observed under trial conditions, by empirical methods. By such an approach it is expected that the following benefits will accrue in a much shorter period of time:

1. By the association of design details to the performance of a ship, improvements may be made in new construction;
2. A "yardstick" for the evaluation of ship vibration characteristics would be made available;
3. A basis for a hull vibration specification would be formed, for the mutual advantage of both builder and operator;
4. A set of industry-approved standards could ultimately be developed and periodically improved when appropriate, to provide ships of consistently improved characteristics.

C. APPROACH

The basis for the establishment of such a vibration criterion or set of norms would fundamentally be the response of the ship girder as a free-free beam. As a secondary basis, the amplification of the hull motion in any local structure would be considered. It would be the ultimate objective to keep the vibration of the hull girder to a minimum as well as the magnification of this motion in the local structures.

The importance of the vibration encountered is of course dependent upon the forces generated, the response of the hull girder and the magnification of the hull girder motion in the local structures of the ship, such as panels, masts, bulkheads, etc. It is reasonable to say that a good design is one in which both the exciting forces and the magnification of these forces in the hull are kept to a minimum. What the reasonable minimum would be for any particular type or class of ship necessarily is dependent on many factors.

By empirical methods, by the collection of existing data, and by obtaining test data during the builder's trials of new ships, it is proposed to:

- (1) Develop "Norms" for various classes of ships; and
- (2) Classify the important design factors which contribute to the general level of vibration existing on any particular class of ship.

On the theory that the acceptable vibration may be based on the considerations of what minimum levels have been obtained on a given type or class of ship as well as on the physiological response of passengers and crews, it is considered reasonable and practical that this program will produce a set of suitable recommendations for the guidance of ship designers and shipbuilders, in developing ships having more satisfactory vibration characteristics.

D. PROGRAM

The "Norm" Program was planned in three phases:

Phase 1 – Conduct vibration tests on several ships to establish a "Vibration Trial Code" and specifications for a "Standard Instrumentation Package."

Phase 2 – Obtain acceptance of the Trial Code by the Society; find sponsorship for the purchase of the instrumentation package; and establish a method for conducting standard vibration tests on a large number of ships.

Phase 3 – Conduct statistical treatment of vibration data collected in accordance with the procedure developed under Phase 2; establish vibration reference levels or "norms" for various classes of ships tested in accordance with the requirements of the Vibration Code; and attempt correlation of vibration levels with design data.

As of this writing Phase 1 has been completed. The "Vibration Code" has received the approval of the Hull Structure Committee and appears as Section III of this report on the SNAME HS-2-1 Program. The Maritime Administration has indicated a willingness to support the purchase of the "Standard Instrumentation Package" and purposes to call for the necessary vibration tests to be included as a part of the builder's trials for all ships built under the sponsorship of the Maritime Administration.

II. LONG-RANGE OBJECTIVES

The Long-Range Objectives of the HS-2-1 Program is frequently referred to as the Rational Approach to the design of vibration-free ships. The principal aspects of the program include:

1. The development of the relationships between hydrodynamic forces and structural response. This work naturally includes the hydrodynamic studies carried out under the H-8 Panel.
2. The development of conversion techniques for design purposes. This aspect of the program includes the prediction of the exciting forces and the structural response of the ship to these forces.
3. The publication of design guides, through SNAME. In a manner similar to that employed in the TMB Program, it is planned to develop an analytical procedure which would permit the review of the vibration characteristics of a proposed design while still in the preliminary design stage.

Significant areas which still require development include:

1. Virtual Mass
2. Damping
3. Propeller Forces (Hydrodynamic and Mechanical)
4. Vibration Reference Levels (Based on the "Norm" Program)

The virtual mass and damping studies will naturally be restricted to those individual cases in which vibration generator tests and detailed analyses can be carried out. The bulk of this work will have to be borne by the Navy Department and the Maritime Administration, as is presently being done in the studies of NS SAVANNAH and in the past on SS GOPHER MARINER.

As a supplement, however, damping data may be obtained from the anchor drop test requested in conjunction with the tests called for by the "Code for Shipboard Vibration Measurements." The oscillograph records will be turned over to the HS-2-1 Task Group for processing.

At the present time a cooperative effort, sponsored by the HS-2-1 Task Group and the H-8 Panel, will be carried out in 1964 on a commercial tanker, through the cooperation of the Humble Oil Co. This study is aimed at the determination of the forces which enter the hull through the water and through the shaft bearings. The cost of instrumentation and testing will be borne largely by the Navy but hopefully, this limited program will start a program of cooperation between The Society of Naval Architects and Marine Engineers and the Maritime Industry in the U. S.

The vibration reference levels which would be used in assessing the adequacy of a proposed design will be based on the "Norm" Program which has been fully described in the previous section. This program is well underway. What remains at this writing, however, is the development of a method of treatment of the data collected to compute the "Norms." Efforts are underway at this time. However, suggestions from the committee members would be gratefully received.

TECHNICAL AND RESEARCH BULLETIN No. 2-10

CODE FOR SHIPBOARD HULL VIBRATION MEASUREMENTS

Prepared by

TASK GROUP HS-2-1 (VIBRATION)
OF
PANEL HS-2 (DYNAMIC LOADINGS AND RESPONSES)
HULL STRUCTURE COMMITTEE

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I. CODE FOR SHIPBOARD HULL VIBRATION MEASUREMENTS

OBJECTIVE

The objective of this code is to establish standard procedures for gathering and interpreting data on hull vibration in single screw commercial ships. These data are needed for comparison of the vibration characteristics of different ships, for the establishment of vibration reference levels for this type of ship, and to provide a basis for the improvement of individual ships.

SCOPE

This procedure is concerned only with the forced vibration excited by the ship's propulsion system, and is therefore restricted to vibration associated with shaft frequency, propeller blade frequency, harmonics of propeller blade frequency, and with frequencies associated with the major components of machinery, such as engine rpm.

FACTORS AFFECTING TEST REQUIREMENTS

In general, comparative data can best be obtained under the more uniform conditions prevailing during ship trials with known ballast loading.

Since the relatively uniform vibrations resulting from propulsion machinery excitation can be masked or distorted by transient vibrations resulting from wave impact or slamming, it is important that vibration testing be conducted in fairly quiet water. Changes in wake distribution due to rudder angle and yaw can produce large increases in exciting forces. Their effect must be determined during controlled maneuvers and minimized during free-route measurements. Propeller emergence, whether periodic, as a result of wave action, or continuous, causes large increases in exciting force and should be avoided during test.

Operation in shallow water has a significant effect on hull vibration. Experience indicates that a depth of at least 5 times ship draft should be maintained during trials, to insure that reasonably accurate data are obtained.

The principal response of the ship's hull to the periodic forces of its propulsion system is similar to that of a free-free beam. Since the extreme stern is an antinode for all bending modes of vibration for this beam, and since the mode shapes for bending vibration are similar for commercial single-screw ships, the stern is an appropriate reference point for measurement of beam-like vibration.

In general, the response of local structure can be evaluated in terms of the ratio of its vibratory amplitude to the amplitude of hull girder vibration at that point.

Alternating thrust forces produced by the propeller may cause dangerous thrust bearing or machinery vibration as a result of longitudinal resonance in the propulsion system. This possibility may be evaluated by determining amplitudes of longitudinal vibration at the thrust bearing housing throughout the normal operating range of RPM.

The study of hull vibration is severely limited by the lack of information on ship damping. The frequencies of the first few vertical modes can usually be determined by an anchor-drop and snub test and the damping constants can be readily obtained from the decay curves of the oscillograph records. The mode number of the lowest frequency measured in the free-route test can often be determined by comparison with the anchor-drop and snub test. The oscillograph data can, if forwarded to The Society of Naval Architects and Marine Engineers, be used to supplement existing information on ship damping.

TEST REQUIREMENTS

a. The test should be conducted in a depth of water at least five times the draft of the ship, and deeper if possible.

b. The test should be conducted in sea state three or less.

c. The ship shall be ballasted to a displacement within the normal operating range, and to a draft aft which will insure at least 2 ft. immersion of the propeller in calm water.

d. During the free-route portion of the test, rudder angle shall be restricted to 2° port or starboard.

e. Measurements should be taken at the following locations:

(1) Stern - Vertical and athwartship measurements, as close to the centerline and to the after perpendicular as possible. Use of bitts, chocks or other fittings attached to deep frames or heavy stiffeners will insure obtaining the motion of the hull girder.

(2) Main thrust bearing foundation - Fore and aft measurements, to determine the response of the shafting system to alternating thrust forces. Vertical and athwartship measurements should also be made to obtain local response of the thrust bearing foundation.

(3) Other local sub-structures as desired - When evidence of local resonance occurs, measurements should be made to form the basis for determining the need for stiffening.

(4) Deck traverse (Optional) - Where required to identify a particular hull mode, vertical amplitude should be measured on the main or strength deck level, on the centerline, at a sufficient number of points to permit determining the approximate location of all nodes. If instrumentation permits, use of both a roving pickup and a fixed pickup at the stern will simplify location of nodes by detecting phase changes.

f. The quantities to be measured are:

(1) Displacement amplitude, in mils single amplitude ($\pm .001$ in.).

(2) Wave form (recorded by the oscillograph).

(3) RPM (by the addition of a time marker, or through the known paper speed. Actual RPM can usually be computed from the oscillograph record. It is desirable, in addition, to record the RPM obtained from the ship's instruments).

(4) Frequencies (obtained from the oscillograph record). Measurements should be made by an electronic system which produces a permanent record, and preferably consisting of velocity-type transducers (which produce a signal proportional to velocity), integrator, amplifier and recorders.

TEST PROCEDURE

a. Determine principal ship characteristics. (a good example of the desired detail is given in the Sample Test Report).

(1) Ship dimensions

(2) Propeller type, dimensions and number of blades.

(3) Propeller aperture clearances.

(4) After-body configuration (include about one-fourth the length of the ship).

(5) Power plant description.

(6) SHP, RPM and speed for various ratings at specified displacement.

(7) Shaft train dimensions (shaft material and diameter, bearing locations, and method of thrust bearing attachment).

b. Record test conditions.

- (1) Displacement.
- (2) Drafts fore and aft.
- (3) Loading or ballasting plan.
- (4) Minimum depth of water.
- (5) Sea state estimate.

c. Calibrate recording equipment.

(1) System calibration - This should be done ashore before every test. A positive-displacement mechanical calibrator should be used to obtain overall system calibration factors.

(2) Electrical calibration - At approximately 30-minute intervals during the test, an electrical calibration signal of known strength should be recorded to permit compensation for any variation in signal gain (the Sample Test Report shows an acceptable method of accomplishing this calibration).

d. Take data during the following conditions:

- (1) In free route, at 5 rpm increments from 1/2 speed to maximum speed.
- (2) Hard turn to port, at maximum speed.
- (3) Hard turn to starboard, at maximum speed.
- (4) Crash-back (from full power ahead to full power astern).
- (5) Anchor drop-and-snub test.

e. Procedures for taking data.

(1) For steady speed, straight course runs, permit ship to steady on speed. Take sufficient length of record to permit collection of maximum and minimum values (about one minute).

(2) For maneuvers, start the recorder as the throttle or wheel is moved. Allow to run until maximum vibration has passed. This normally occurs when ship is dead in the water during crash-back maneuver, or when the ship is fully in a turn.

(3) For the anchor drop-and-snub test, the anchor must fall freely for a distance of no more than 15 fathoms but at least equal

to twice the draft of the ship, and must be snubbed quickly by use of the windlass brake; and must not touch bottom. The ship must be dead in the water for this test, with a minimum of rotating equipment in operation. Care should be taken not to exceed the anchor windlass manufacturer's recommendations for free drop. Data should be taken continuously from the moment the anchor is released until vibration can no longer be detected.

ANALYSIS AND REPORTING OF DATA

a. Analysis shall provide the following information for all runs:

- (1) Maximum overall values of amplitude.
- (2) Maximum amplitude of first-order (shaft-frequency) vibration.
- (3) Maximum amplitude of blade-frequency vibration.
- (4) Maximum amplitude at each detectable harmonic of blade frequency.
- (5) Maximum amplitude at hull resonant frequencies.

Maximum amplitude is defined as the average of the highest 10% of all amplitudes at a given frequency which are present in a vibration record. For reducing oscillograph data, the procedures given in "Waveform Analysis," by R. G. Manley (John Wiley & Sons, Inc., 1946) are recommended.

b. Data reported shall include the following:

(1) A tabulation of all results, following the outline of Table 1, for both Free Route (straight course) and Maneuvering Runs.

(2) Separate curves of single-amplitude of displacement vs. RPM, for the following Free Route measurements:

- a) Vertical hull vibration.
- b) Athwartship hull vibration.
- c) Vertical vibration of thrust bearing foundation.
- d) Athwartship vibration of thrust bearing foundation.

e) Fore and aft vibration of thrust bearing foundation.

f) Any other structural vibration deserving of record.

(3) Oscillograph records of the anchor drop-and-snub test should be submitted directly to The Society of Naval Architects and Marine Engineers Hull Structure Committee. If they do not contain a time indicator, the paper speed at which they were recorded should be noted on each record.

c. Characteristics of the instrumentation used in the test shall be reported as follows:

(1) Component identification.

(2) Block wiring diagram.

(3) Calibration curves.

(4) Exact location of pickups.

d. The test report shall note the hull natural frequencies which were identified, and shall also mention any undesirable or unusual vibration condition encountered.

TEST REPORT FORM

AVERAGE MAXIMUM AMPLITUDE (MILS, SINGLE AMPLITUDE)

Date of Test _____

Sea State _____

a. STEADY SPEED (STRAIGHT COURSE) RUNS

Run No.	*Shaft Speed RPM	Depth Feet	Frequency cpm	Order	Stern		Thrust Bearing Foundation	
	Vert.				Athw.	F&A	Vert. Athw.	

b. HARD PORT TURN

c. HARD STARBOARD TURN

d. CRASH-BACK

* Record for Test (a) only. Ship will be at maximum speed at start of all maneuvers (b--d).

II. SAMPLE TEST REPORT

GENERAL

The information presented herein is taken from The Society of Naval Architects and Marine Engineers' Report "Vibration Measurements on Ship S6-4 during builder's trials." Specific references to the owners and shipbuilders have been omitted.

Although detailed trial agendas will vary from ship to ship, the procedure employed on "Ship S6-4," is considered typical for vibration tests conducted under The Society of Naval Architects and Marine Engineers developed program. Qualifying notes are added in the sample report, as required.

SHIP CHARACTERISTICS

The ship is a single screw cargo ship, built by the ----- Shipbuilding Corporation. An inboard profile is shown in Figure 1. Principal dimensions are as follows:

Length:	Overall	572'0"
	Between Perpendiculars	541'0"
Breadth:		75'0"
Depth:		42'6"
Draft:		30'6"
Tonnage:	Deadweight	12,700 Tons
	Maximum Displacement:	20,110 Tons
	Block Coefficient:	.57

A. MAIN ENGINE DESCRIPTION

The main engine consists of one high and one low press steam turbine arranged in the installation to form a cross-compound-type unit. Both turbines are equipped with eight stages for ahead operation. In addition, the low pressure turbine is equipped with two stages for astern propulsion. Each reverse stage carries a double row of blading. The two turbine rotors are connected through flexible couplings to the MD-97-D, double helix, double reduction gear, which is connected to the propeller shafting.

For ahead operation the unit is rated at 16,500 SHP at approximately 105 RPM (Normal) and 18,150 SHP at approximately 108 RPM, when supplied with steam at 585 psig, 840^o F. and exhaust vacuum of 28.5" Hg.

When operating astern, the turbine-gear set will develop 80% of rated ahead torque at 50% of ahead speed with rated steam conditions, and may be operated continuously at a speed not in excess of 70% of rated ahead RPM at 2.5 inches Hg abs.

B. REDUCTION GEAR DESCRIPTION

The speed reducing unit between the turbine and the propeller is a double-reduction, double-helical gear.

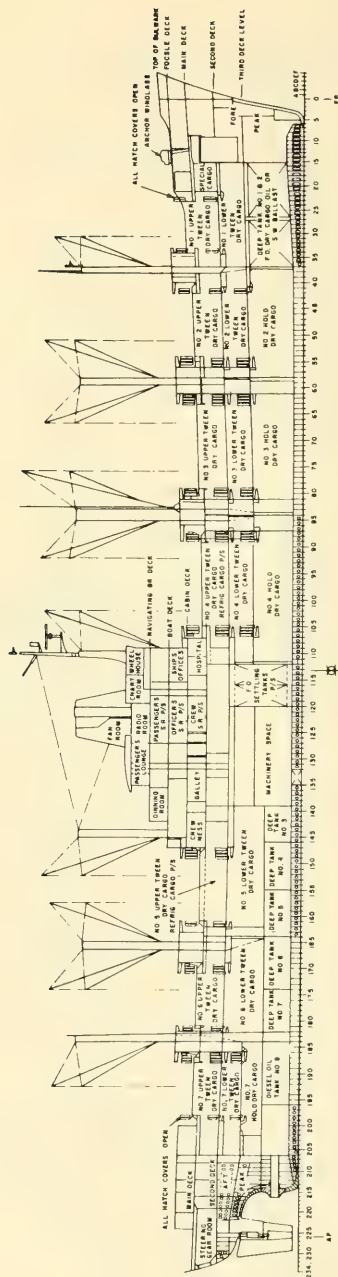


Figure 1 - General Arrangement Inboard Profile Ship "S6-4"

<u>CHARACTERISTIC</u>	<u>NORMAL RATING</u>	<u>MAXIMUM RATING</u>	<u>MILITARY RATING</u>
Shaft Horsepower	16, 500*	18, 150	23, 500
Shaft RPM			
HP Turbine	6, 334	6, 515	7, 119
LP Turbine	3, 689	3, 794	4, 146
1st Red. H. P.	811	834	911
1st Red. L. P.	641	659	720
Propeller	105*	108	118

* At rated steam condition.

The rotating elements of the gear consist of two first-reduction pinions, two first reduction gears, two second-reduction pinions, and one main gear.

C. THRUST BEARING DESCRIPTION

The propeller thrust, in both the ahead and astern directions, is transmitted by a main thrust bearing located immediately aft of the main reduction gear. This bearing is located in the vicinity of frame number 137, approximately 220 feet forward of the aft perpendicular.

D. PROPELLER DESCRIPTION

A four bladed propeller, 21 feet in diameter and having a pitch of 21.61 feet at .7 radius is used to develop a maximum of 23,500 SHP at 118 rpm.

Estimated speed and power ratings at trial displacement of 11,560 tons:

	<u>NORMAL POWER</u>	<u>MILITARY POWER</u>
Propeller RPM	109.2	120.4
Shaft Horsepower	16, 500	23, 500
Speed, Knots	24.0	25.7

Propeller aperture clearances, as calculated from ship drawings, are given in Figure 2.

The lines, showing the stern configuration of Ship S6-4 are given in Figure 3.

BALLAST PLAN ON SEA TRIALS

<u>TANKER NUMBER</u>	<u>FRAME NUMBER</u>	<u>CONTENTS</u>	<u>TONS</u>	<u>CONDITION</u>
<u>Fuel Oil Tanks</u>				
Settler Fwd. - P/S	112-116	F. O.	150	Slack
Settler Aft - P/S	116-120	F. O.	17	Slack
D.B. No. 4 - C.L.	84-112	F. O.	244	Full
D.B. No. 4 - P/S	84-112	F. O.	299	Full
D.B. No. 5A- C.L.	122-139	F. O.	127	Full
D.B. No. 5A- P/S	122-139	F. O.	182	Full
D.B. No. 6 - C.L.	139-164	F. O.	218	Full
D.B. No. 6 - P/S	139-164	F. O.	138	Full
D.B. No. 7 - P/S	164-184	F. O.	75	Slack
			<u>1450</u>	

Fresh Water Tanks

D.B. No. 5F - C.L.	113-121	F. W.	37	Slack
D.B. No. 5F - P/S	113-121	F. W.	105	Full
Distilled Water Tank	113-139	F. W.	12	Slack
Portable Water Tank	113-139	F. W.	25	Slack
			<u>179</u>	

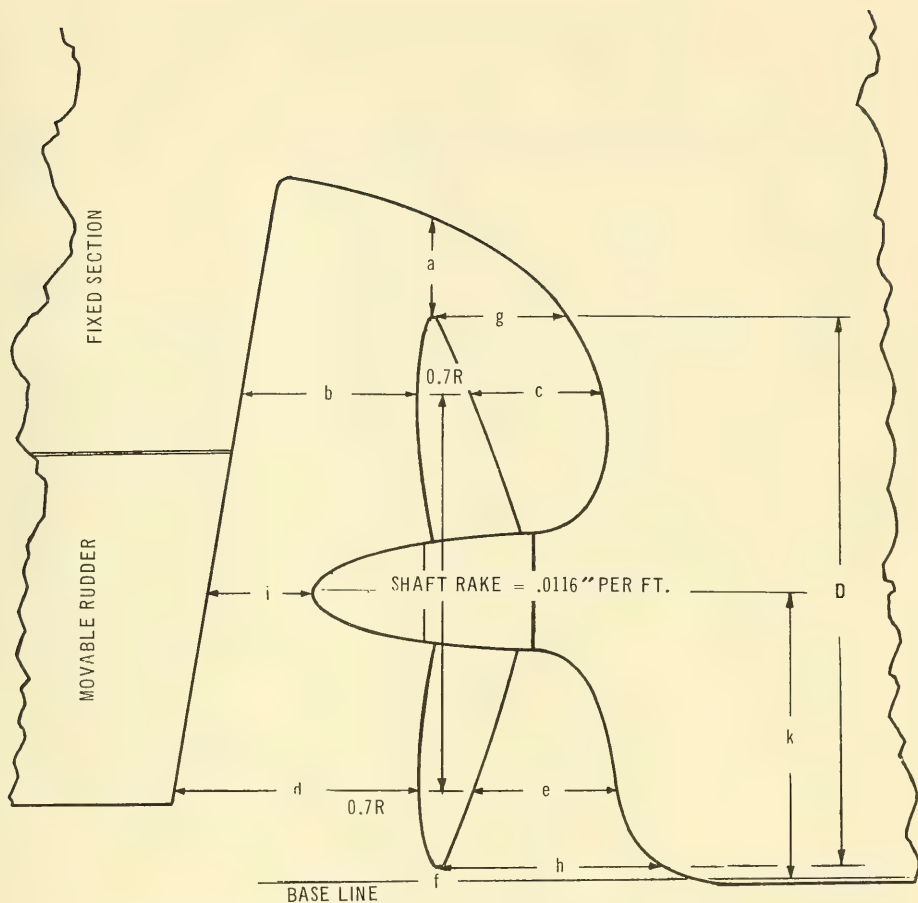
Fuel Oil or Ballast or Cargo Oil Tanks

D.B. No. 1 - C.L.	15-37	F. W.	71	Full
D.B. No. 2 - P/S	37-38	F. W.	130	Full
D.B. No. 3 - P/S	58-84	F. W.	355	Full
Fore Peak	Stem-15	F. W.	90	Full
D.T. No. I - C.L.	15-27	F. W.	180	Full
D.T. No. II - C.L.	27-37	F. W.	255	Full
D.T. No. III - P/S	139-146	F. W.	345	Full
D.T. No. IV - P/S	146-155	F. W.	400	Full
D.T. No. V - P/S	155-164	- -	- -	Dry
D.T. No. VI - P/S	164-174	- -	- -	Dry
D.T. No. VII - P/S	174-184	F. W.	185	Full
D.T. No. VIII - P/S	184-196	- -	- -	Dry
Aft Peak	206-222	S. W.	300	Full
			<u>2311</u>	

Summary of Drafts, Weights and Displacements

	<u>Leave Yard *</u>	<u>Trial Cdn.</u>
Light Ship, Crew & Effects, Stores	7,620	7,620
Fuel Oil	1,450	1,450
Fresh Water	179	179
Ballast	2,011	2,311
Total Displacement - - - -	<u>11,260</u>	<u>11,560</u>
Draft Forward	15'8"	14' 3"
Draft Midship	18'5"	18'10"
Draft Aft	21'2"	23'5"

* Aft Peak Tank Empty



NUMBER OF PROPELLER BLADES = 4

$D = 21$ FT.

$a = 3.83$ Ft.

$b = 6.17$ Ft.

$c = 5.25$ Ft.

$d = 8.93$ Ft.

$e = 6.0$ Ft.

f Not Applicable (No Shoe)

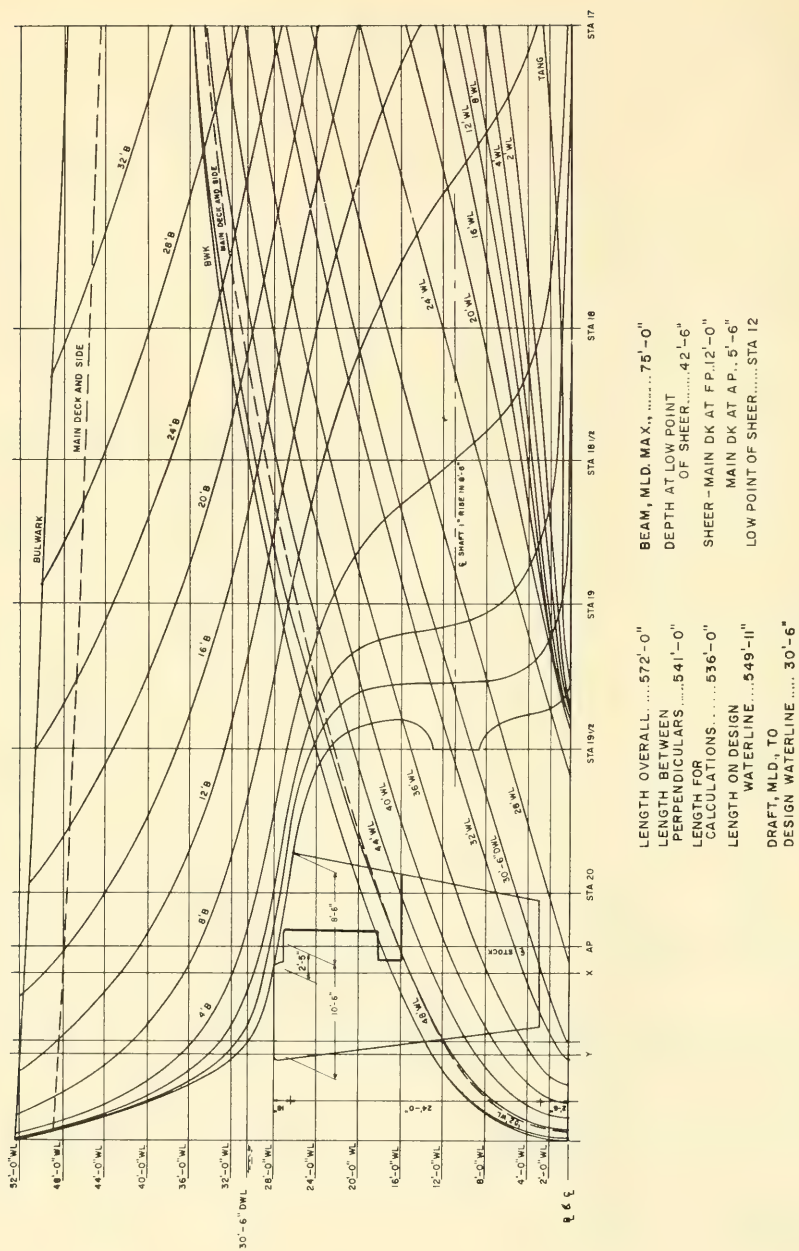
$g = 6.00$ Ft.

$h = 9.68$ Ft.

$i = 3.67$ Ft.

$k = 10.75$ Ft.

Figure 2 - Propeller Aperture Clearances (From Drawings)



INSTRUMENTATION

(Note: If the standard instrument package available from the Maritime Administration is used, a standard write-up will be provided for this section.)

Figure 4 shows the block diagram of the electronic instrumentation used on this survey.

The MB Vibration Pickup is an electromagnetic seismic instrument which generates a voltage proportional to the velocity of vibration. As shown on Figure 4, this voltage is passed through an NKF Integrator to convert velocity to displacement, and amplified by the Ballantine Decade Amplifier. This displacement signal is then recorded through the Edin Amplifier and Oscillograph.

Two types of MB pickups were used: the type 120 and the type 124. These pickups are similarly constructed and have the same nominal sensitivity of 94.5 mv per inch/sec. The type 120 has a natural frequency of 2.25 cps, as compared with a frequency of 4.75 cps for the type 124. Thus, the type 120 would be useable at a lower frequency.

A brief description of each component of the electronic instrumentation follows:

1. MB type 120 Velocity Pickup
Velocity sensitivity = 94.5 mv/in/sec.
Flat Frequency from 5 to 1000 cps.
Electro-magnetic damping = 0.65 critical.
2. MB Type 124 Vibration Pickup
Velocity sensitivity = 94.5 mv/in/sec.
Flat Frequency from 8 to 1000 cps.
Electro-magnetic damping = 0.65 critical.
3. NKF Selector Switch - provides means for switching any of 12 different input signals into either of two recording channels.
4. NKF Integrator - provides two channels of either single or double integration.
5. Ballantine Decade Amplifier Model 220B - is used to amplify the transducer output voltage before integration. This amplifier can be set to either 10x or 100x amplification. An amplification of 10x was used during this survey.

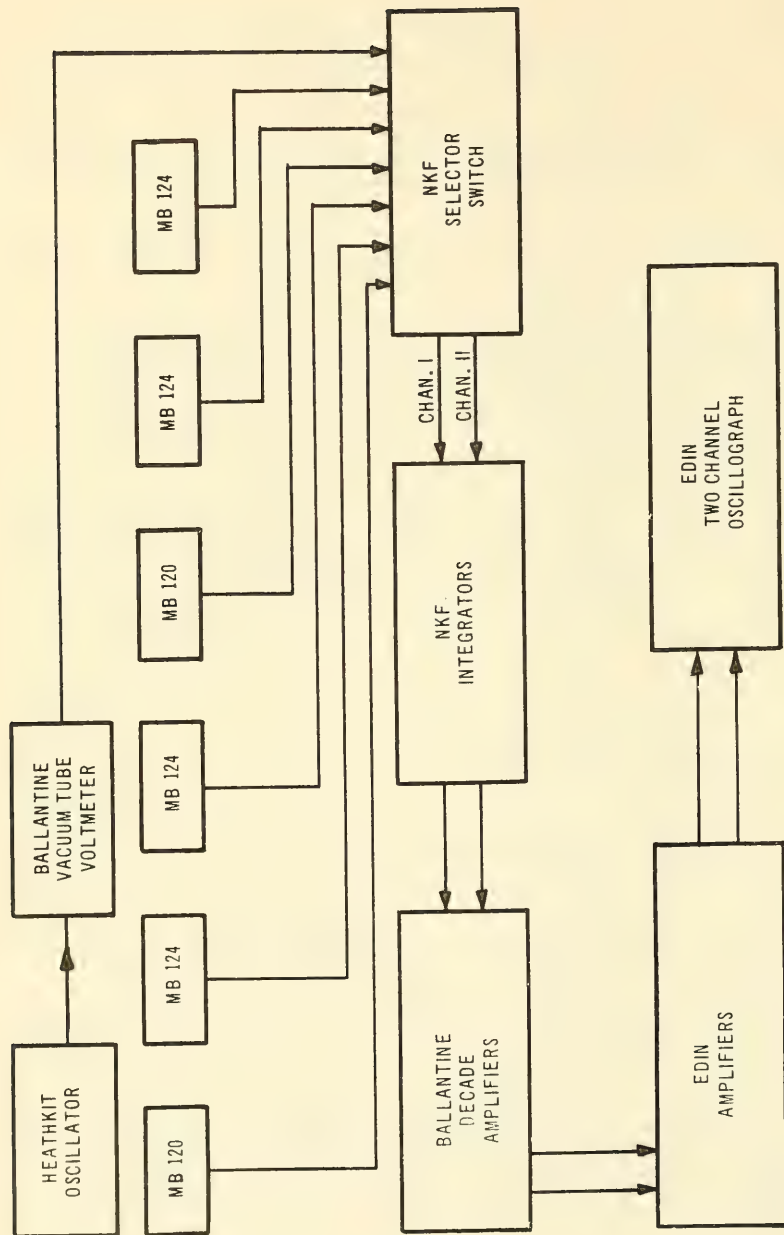


Figure 4 - Electronic Instrumentation for Linear Vibration Measurements

6. Edin Amplifier Model 8105 - is a stable high gain D.C. amplifier with means for attenuating the signal to provide the desired size recording on the oscillograph.

7. Edin Oscillograph Model 8062 - is a direct writing two channel oscillograph, with three paper speeds, 5, 25 and 125 mm/sec. A paper speed of 25 mm/sec. was used for most of this survey. A solenoid operated events marker was added to provide the common timing and synchronizing pulse.

8. Heathkit Oscillator - provides the calibration signal.

9. Ballantine Vacuum Tube Voltmeter is used to monitor the calibration signal.

Frequency checks were accomplished by the use of constant paper speed on the oscillograph. In most cases a speed of 25 mm per second was used. On occasion however, a paper speed of 125 mm per second was used.

The pickups were installed on tri-axial brackets which were clamped to the main thrust bearing foundation and to an angle welded to the deck over the main transverse member at the aft-perpendicular in the steering engine room. Figures 5 and 6 show the pickup clusters. The instrumentation was installed in the workshop just forward of the steering engine room. Figure 7 shows the instrumentation arrangement.

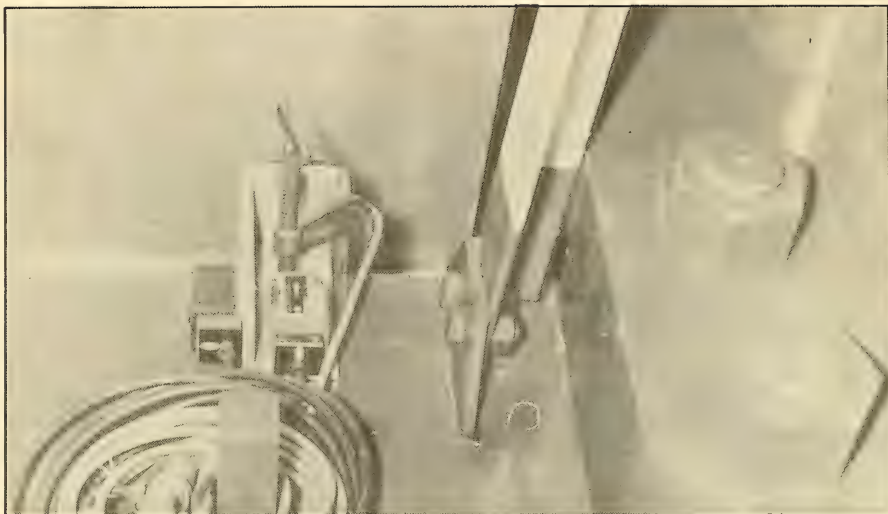


Figure 5 – Pickup Cluster – Main Thrust Foundation

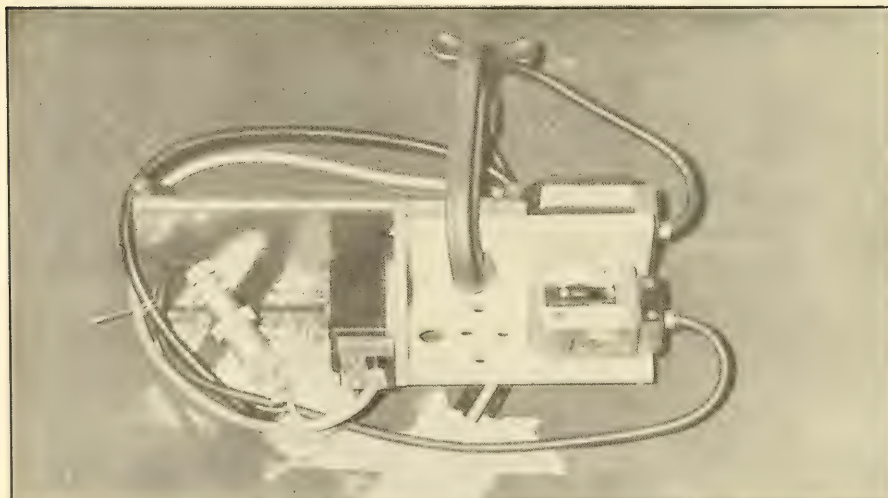


Figure 6 – Pickup Cluster – Fantail

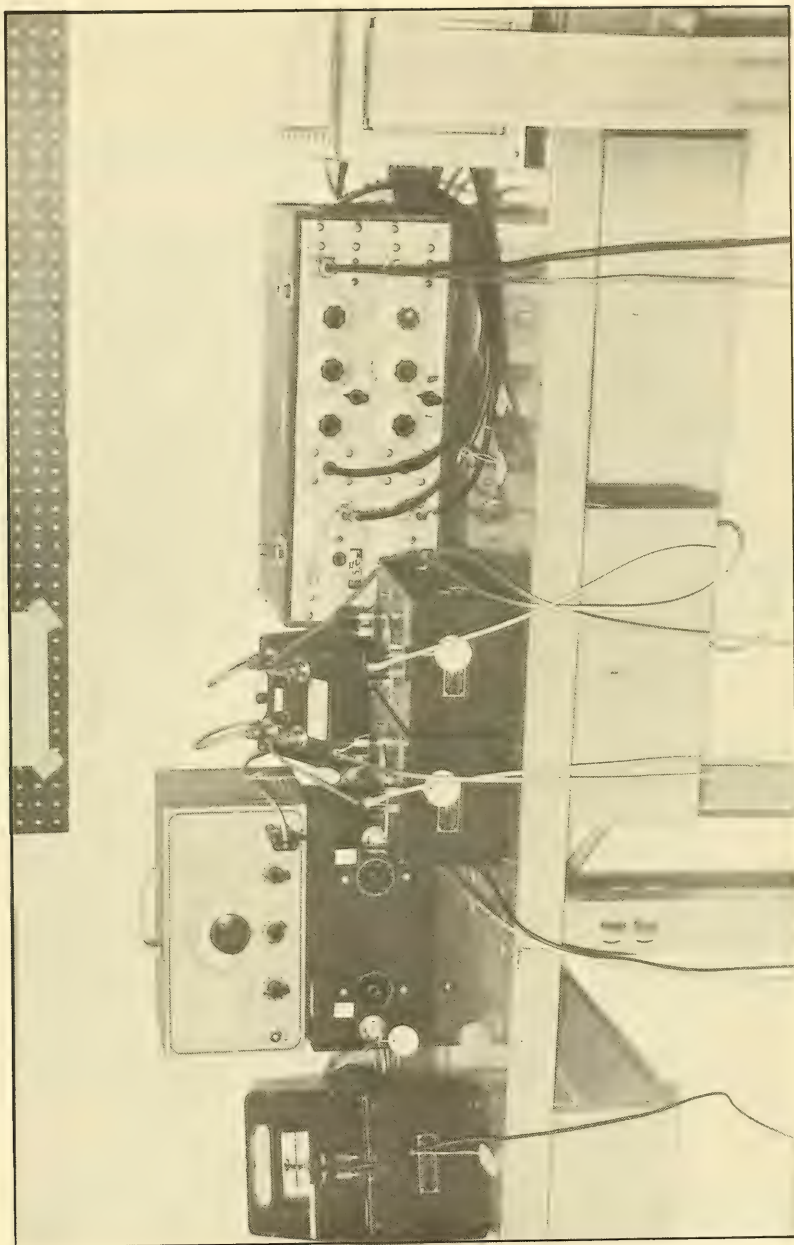


Figure 7 — Instrumentation Arrangement

CALIBRATION

(Note: If the standard instrument package available from the Maritime Administration is used, a standard write-up will be provided for this section.)

The MB Vibration Pickups were calibrated on the NKF Scotch Yoke Calibrator. This calibrator is a motor driven shaker. The impressed amplitude was ± 50 mils. A variable speed control provides the frequency adjustment. A range of 1 to 20 cps was used during the calibrations.

The transducer outputs were fed into the electronics shown on Figure 4. A convenient technique was used for maintaining calibration of this system throughout the calibration runs and the actual test runs. With the application of a known signal from the oscillator, monitored by the vacuum tube voltmeter, the signal size on the oscillograph chart is maintained constant by a simple adjustment of the sensitivity dial on the Edin Amplifier. Thus checks are possible after each run and any variation in gain of the system, can be readily compensated.

Figures 8 and 9 show the calibration curves for the pickups used.

The calibration factor is used to determine the amplitude of vibration by insertion in the following expression:

$$\text{Amplitude } \pm \text{ mils} = \frac{\text{D.A.} \times \text{Attenuation Setting}}{\text{Calibration Factor}}$$

Where:

D.A. = double amplitude in millimeters, as measured
on the oscillograph record

Attenuation setting = attenuation setting of the Edin
Amplifier as used on any particular run.

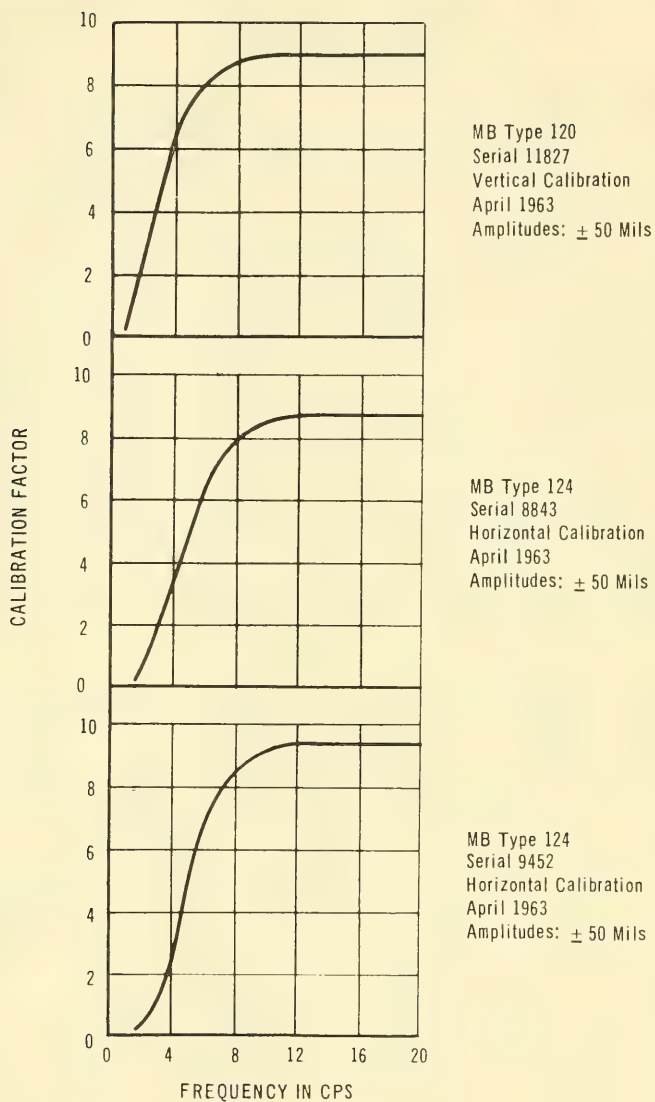


Figure 8 - Calibration Curves - Stern

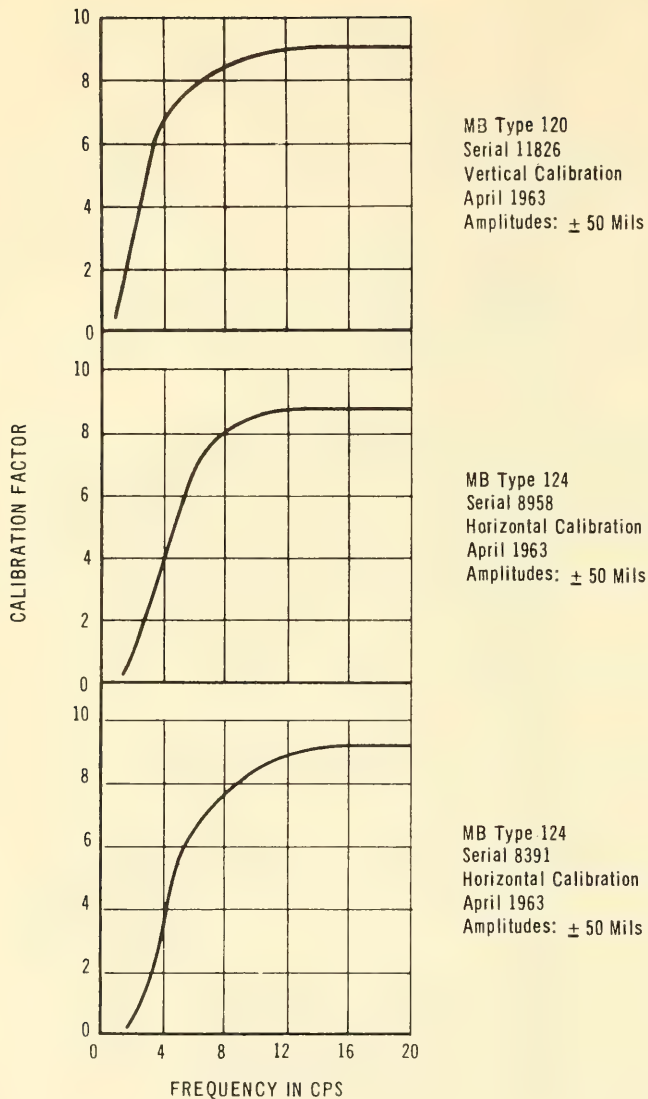


Figure 9 - Calibration Curves - Thrust Bearing Foundation

TEST PROCEDURE

(The test procedure was designed to permit data collection during the Builder's Trials with minimum interference with the scheduled program. As the ship left the yard data were taken in shallow water and with the Aft Peak Tank empty. Drafts and displacements are given under Ship Characteristics.) **

The remainder of the test program was conducted in deep water with the Aft Peak Tank full. The displacement during these tests was estimated at 11,560 tons. Actual conditions and drafts are given under Ship Characteristics and Ballast Plan on Sea Trials. Throughout the test the sea condition did not exceed Sea State 1.

During the steady speed runs, data were taken at 5 rpm increments, between 80 rpm and full power. Data were also taken at specific operating speeds which were equivalent to the Normal, Maximum, and Military ratings of the propulsion system. During the remainder of the test conditions, data were taken at the convenience of the ship. For coordination, phone communications were established between the test compartment, the engine room and the bridge by the use of a temporary circuit.

(Note: If the Maritime Administration Instrument Package is used, the following procedure is simplified since all channels are recorded simultaneously.)

The recording system used permitted data taking on two channels simultaneously, as noted under Instrumentation. For convenience, three runs were made at each speed increment during the constant speed runs. The sequence of operation is shown in the following table, together with the switch position and the corresponding pickup location:

RECORDING PROCEDURE

<u>Run</u>	<u>Switch Position</u>	<u>Pickup Location</u>	<u>Pickup No.</u>
A	I* - 1	Stern - Vertical	11827V
	II - 4	Thrust Bearing Foundation - Vertical	11826V
B	I - 2	Stern - Athwartship	8843H
	II - 5	Thrust Bearing Foundation - Athwartship	8958H
C	I - 3	Stern - Fore & Aft	9452H
	II - 6	Thrust Bearing Foundation - Fore & Aft	8391H

* Roman numeral applies to recording channel.

** Shallow water data not required.

For the anchor drop-and-snub test, vertical measurements were made at the Stern and Thrust Bearing Foundation when the star-board anchor was dropped. Data was taken continuously during the anchor drop test while the anchor was repeatedly paid-out and snubbed.

During the maneuvering runs, data were obtained on the Stern in the vertical direction and at the Thrust Bearing Foundation in the fore and aft direction. During stern operation and crash ahead condition, channel II was switched from fore and aft response at the Thrust Bearing Foundation, to athwartship response of the Stern.

DATA REDUCTION PROCEDURES

(Note: If the standard instrument package available from the Maritime Administration is used, a standard write-up will be provided for this section.)

The methods employed in reducing the test data is of equal importance to the proper choice of instruments, adequate calibration and suitable test procedure. Since the vibration present in the hull of a ship does not remain at a constant level, but rather increases and decreases, it is most important that a standard technique be employed in the evaluation of data for comparative purposes.

In this program, the maximum value is taken as the average of the highest 10% of all amplitudes at a given frequency. Thus, only those sections of the oscillograph records which show the largest amplitudes need be reduced.

The measurement of the amplitudes on the records themselves is considered important. Since the records are not normally evaluated by a formal Fourier Analysis, nor does the evaluation warrant it, it is nevertheless important that a common and acceptable procedure be employed. A sine wave of the predominant frequency should be drawn through the complex wave. Thus, the actual vibration record is replaced by one of mean amplitude. This is particularly apparent in the electronic data which has adequate response and amplification to record most frequencies present. As a practical demonstration of this process, see Manley, R.G., "Waveform Analysis," John Wiley & Sons, Inc., 1946.

TEST RESULTS

The results of the Steady Speed Runs are given on pages 26 and 27. This data is divided into three sections, for the conditions noted:

- (a) Aft Peak Tank Empty - Shallow Water
- (b) Aft Peak Tank Full - Shallow Water
- (c) Aft Peak Tank Full - Deep Water

Ordinarily only the deep water condition would be studied, preferably with the Aft Peak Tank full. In this instance however, further information was desired on the influence of depth of water, displacement, the presence of fluid in the Aft Peak Tank and rudder control. The additional runs for conditions (a) and (b) would not be required in future tests.

The results of the Maneuvering Runs are given on page 28. Since only two channels could be recorded simultaneously, the selections made were as noted under Test Procedure. If a multi-channel system is used in the future, all channels could be then recorded simultaneously. It is recommended however, that only the vertical and athwartship measurements of the stern are important.

The required plots of vibration amplitude versus RPM are shown on Figures 10 through 13.

The anchor drop-and-snub tests permitted the identification of three vertical modes of flexural vibration of the hull at 1.5, 2.75 and 4.93 cps. The main purposes of the anchor drop-and-snub tests are to determine these frequencies and to provide a basis for estimating damping characteristics of ships hulls. Since this latter aspect of the program is more fundamental in nature and not directly associated with the evaluation of the ship's vibration characteristics, no further discussion on the subject is given in this report. On future studies which may be carried out on other ships, it has been proposed that the oscillograph records obtained during the anchor drop-and-snub tests be included with the report. The study of hull damping characteristics may then be undertaken as a separate program.

SHIP S6-4TEST DATA - STEADY SPEED (STRAIGHT COURSE) RUNSAVERAGE MAXIMUM AMPLITUDES (MILS, SINGLE AMPLITUDE)TEST OF 15 APRIL 1963

Run No.**	RPM	Depth Fathoms	Frequ. CPM	Order	Stern			Thrust Bearing Foundation		
					Vert.	Athw.	F&A**	Vert.	Athw.	F&A
<u>Aft Peak Tank Empty - Shallow Water**</u>										
6	90	7	360	4	2.5		.9			
			720	8		1.8	.3			
			1080	12			.2			
9	105	7	420	4	7.0	3.2		2.4	.8	2.1
			840	8	1.1	.7	.2			.2
11	111	7	444	4	4.6	1.1		1.4	.8	2.0
			888	8	.6	1.4	.5	.2	.1	.2
14	112	15	448	4	2.9	1.5		.5	.8	1.5
			896	8	.6	.5	.6			
17	117	15	468	4	4.2	2.5	.6	.5	.7	1.0
			936	8	1.7	.7	.6	.2	.1	.3
<u>Aft Peak Tank Full - Shallow Water**</u>										
53	112	14	448	4	3.2	1.3		.5	.4	1.9
			896	8		1.1	.5			
<u>Aft Peak Tank Full - Deep Water</u>										
23	80		80	1	8.0					
			320	4	1.0			.3		.3
			640	8	.7	.8	.2		.2	.9
24	85		85	1	16					
			340	4	.8		.1	.4		
			680	8	.7	.8	.2		.2	.7
25	90		90	1	38.4					
			360	4	2.7	.6		.5	.1	.2
			720	8		.7			.2	.4
			1080	12			.13			
26	95		95	1	10.7					
			380	4	1.0	2.9		.9	.4	.4
			760	8	.7					.3
			1140	12			.18			
27	100		100	1	6.3					
			400	4	.7	.4		.4	.5	.7
			800	8	1.3	.9				.2
			1200	12			.22			

TEST DATA - STEADY SPEED (STRAIGHT COURSE) RUNS
(continued)

Run No.**	RPM	Freque. CPM	Order	Stern			Thrust Bearing Foundation		
				Vert.	Athw.	F&A	Vert.	Athw.	F&A
28	105	105	1	5.0					
		420	4	1.7	.8		.4	.4	1.6
		840	8	.7	.1			.1	.1
		1260	12			.24			
29	110	110	1	4.4					
		440	4	1.8			.5	.5	1.6
		880	8	1.1	.7	.5			
31	113	150	*	6.6					
		452	4	2.9	1.0		.6	.7	1.6
		904	8	.6		.5			
34-a**	117	90	*	10.7					
		468	4	2.3	2.0		1.2	.8	2.0
		936	8			.3			
35-b**	116	90	*	21.4					
		464	4	2.9	2.0		1.3	.8	2.8
		928	8			.3			
36-c**	116	90	*	14.3					
		464	4	1.4	1.7		1.4	.5	1.9
		928	8		.91	.5			
39	119	90	*	17.9					
		476	4	4.0	2.3		2.2	1.1	3.1
		952	8			.4			
40	120	480	4	6.9	2.5		2.2	1.2	3.4
		960	8			.5			
41-b**	123	492	4	6.2	2.3	.3	2.2	1.1	2.4
		984	8			.5			
43-a**	121	484	4	8.0	2.3		2.2	1.2	2.5
		968	8			.4			
44-c**	121	484	4	7.4	2.2		2.3	1.3	2.3
		968	8			.4			

* Constant Frequency - indicates hull resonance

** Run a - Manual Steering
Run b - Automatic Steering
Run c - Free Rudder

** Not normally required

SHIP S6-4TEST DATA - MANEUVERING RUNSAVERAGE MAXIMUM AMPLITUDES (MILS, SINGLE AMPLITUDE)TEST OF 15 APRIL 1963

Run No.	RPM	Condition	Frequ. CPM	Order	Stern		Thrust Bearing Foundation
					Vert.	Athw.	F&A
46	122	Full Rudder L & R	488	4	6.8		3.7
					11.4		4.9
	119	35° L & Hard Left	165	*	14.0		
			165	*	6.4		
			476	4	12.6		
	113	35° R	90	*	28.6		
	117		165	*	8.1		
	120	35° L	90	*	32.1		
			480	4	11.4		
			90	*	85.7		
47	- -	123 Fwd. to 73 Astern	165	*	37.2		
	67.5A	Astern Operation	270	4	16.6		
	64.5A		258	4	28.5		
	67.5A		630	-			1.7
	64.5A		618	-			1.1
48	- -	0 to 73 Astern	860	-	3.9		
	- -		590	-		2.9	
	72A		90	*	14.3		
	72A		280	4		3.9	
	72A		560	8	2.8	4.1	
50	72A	73 RPM Astern	165	*	1.5		
			288	4		2.1	
51	- -	73 Astern to Stop	90	*	57.1		
	- -		165	*	17.4		
	- -		270	*		17.8	
	- -		330	*	13.3	19.7	
	- -		408	8	5.7	2.0	

* Constant frequency - indicates hull resonance.

- Notes: 1. With the two channel recorder, only the more significant readings were taken.
2. Some doubt exists on the position of the rudder at the time the data was taken during turns.

Test Plots – Vibration Amplitudes versus RPM

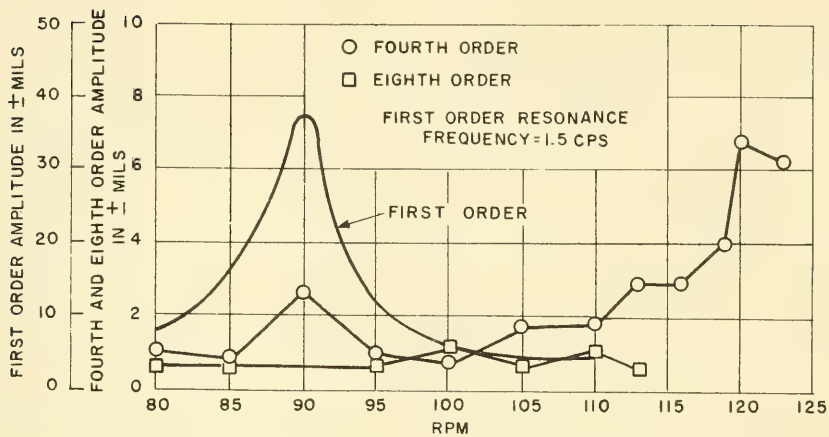


Figure 10 - Vertical Vibration at Stern - Deep Water - Aft Peak Tank Full

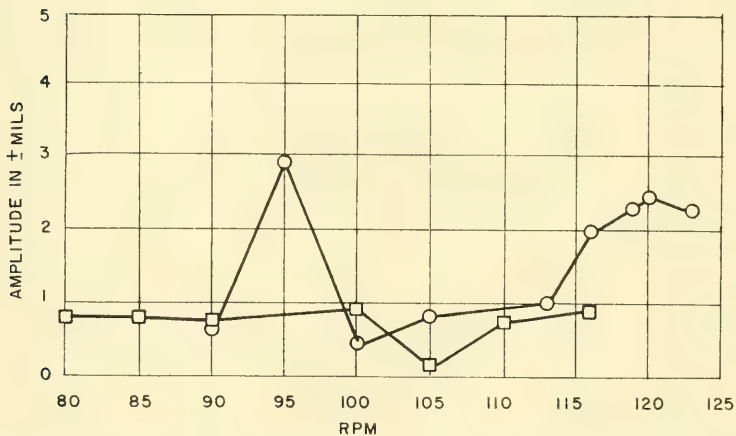


Figure 11 - Athwartship Vibration at Stern - Deep Water - Aft Peak Tank Full

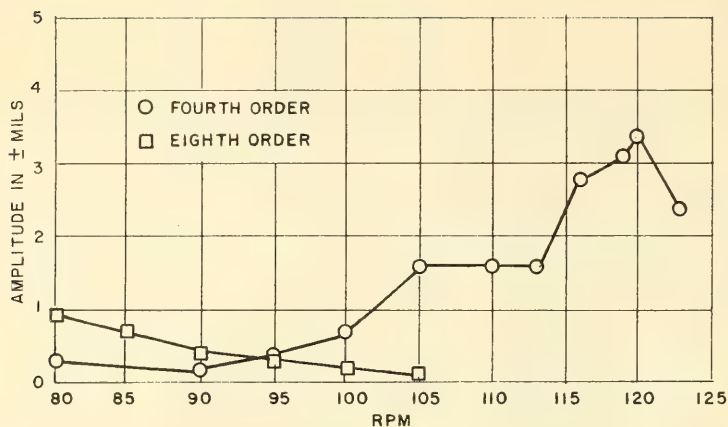


Figure 12 – Fore and Aft Vibration at Thrust Deep Water – Aft Peak Tank Full

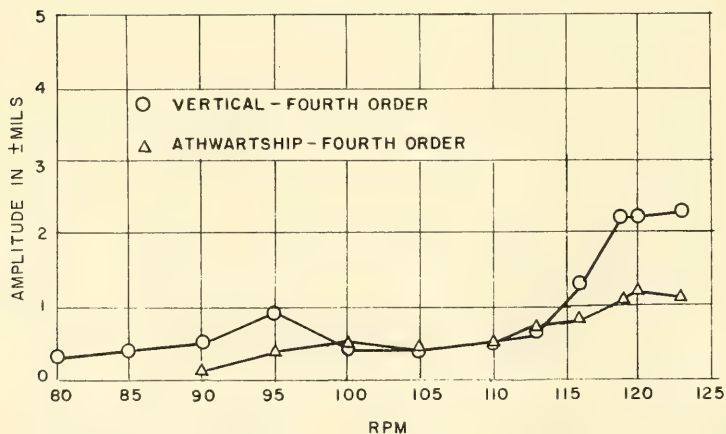


Figure 13 – Vertical and Athwartship Vibration at Thrust Deep Water – Aft Peak Tank Full

PART THREE

BIBLIOGRAPHY OF U.S. SHIP VIBRATION RESEARCH

by

V.S. Hardy and G.P. Antonides

The purpose of this bibliography is to list the publications which document the significant research work done in U.S. on ship vibration. It consists of three sections:

- I. Basic Reports
- II. Ship Structures Reports
- III. Machinery Reports

1. BASIC REPORTS

Adams, Emily J. and Welch, A.R., "Calculations of Flexural Critical Frequencies of Ship Hulls by Prohl's Method," DTMB Report 582, July 1947.

This report extends Prohl's method for the calculation of the flexural critical frequencies of flexible rotors to the calculation of the flexural critical frequencies of ship hulls. The method is simplified and set up so that the computations can be readily made with a punch-card machine.

Adams, Emily J., "The Steady-State Response of a Ship's Hull to a Simple Harmonic Driving Force Computed by a Digital Process," DTMB Report 715, May 1950.

A numerical method of finding the steady-state response of the hull of a ship to a sinusoidal driving force is described. Results of calculations for the vertical flexural vibration of the USS NIAGARA (APA 87) are given and compared with experimental data. It is also shown that the vibration of the hull at a frequency other than one of the natural mode frequencies may be calculated as the sum of the vibrations of the natural modes compounded by a normalization process.

Baier, L.A. and Ormondroyd, J., "Vibration at Stern of Single-Screw Vessels," SNAME Transactions, Vol. 60, p.10, 1952.

This paper is concerned with the problem and elimination of faint vibration as experienced on bulk carriers operating on the Great Lakes; however, it is thought that the solutions evolved are applicable to other types of vessels.

Birmingham, John T., et al., "Statistical Presentation of Motions and Hull Bending Moments of Destroyers," DTMB Report 1198, September 1960.

The motions and the longitudinal hull bending moments that a destroyer of the DD 592 Class is expected to experience over a wide range of operating conditions are presented in statistical form. Criteria are derived for use in design and operational problems.

Breslin, J.P., "A Theory for the Vibratory Effects Produced by a Propeller on a Large Plate," Journal of Ship Research, Vol. 3, No. 3, p.1, December 1959.

The flow generated on an infinite plane or wall by a single-bladed ship propeller rotating on a shaft parallel to the plane in a uniform superposed stream is first considered, and the case of non-uniform inflow is then considered and shown to give nonzero vibratory forces.

Breslin, J.P., "The Unsteady Pressure Field near a Ship Propeller and the Nature of the Vibratory Forces Produced on an Adjacent Surface," Stevens Institute of Technology, ETT Report 609, June 1956.

Forces on a flat plate were calculated in a uniform flow when a single-line vortex passed the plate. The calculations were for the two-dimensional problem. Results show that clearances behind the vortex are not as important as clearances ahead of the vortex, or clearances between hull and propeller are more significant than those between propeller and rudder.

Breslin, J.P. and Tsakonas, S., "Marine Propeller Pressure Field Due to Loading and Thickness Effects," SNAME, Vol. 67, p. 386, 1959.

This paper deals with the total field produced by blade-thickness effects as well as that due to loading. This is a new treatment of the pressure field. It has produced closed form answers in terms of tabulated elliptic integrals to replace the numerical harmonic analysis formerly employed.

Buchmann, E., "Criteria for Human Reaction to Environmental Vibration on Naval Ships," DTMB Report 1635, June 1962. Also published in Proceedings of Institute for Environmental Sciences, June 1962.

This report presents the results of an extensive search of existing literature on human reactions to vibration. Vibration norms for human reaction are suggested.

Buchmann, E. and McConnel, J.D., "Environmental Conditions of Ship Motions and Vibrations for Design of Radar Systems on Destroyers and Aircraft Carriers," DTMB Report 1298, July 1959.

Rigid-body motions and vibrations measured over a long period of time and a wide range of operating conditions, are used to determine the environmental conditions of vibration and ship motion for use in the design of radar installations. Extreme values for ship motions in severe seas are predicted. Application of the data to design problems are discussed.

Gatewood, J. W., "The Period of Vibration of Steam Vessels," SNAME, Vol. 23, p.119, 1915.

The basis of this paper is that, by changing the loading of the vessel where the vessel is considered to act like a beam, the period of vibration is automatically changed. Computations are given for the periods of vibration when the ship is represented as a beam.

Jasper, N.H., "A Design Approach to the Problem of Critical Whirling Speeds of Shaft-Disk Systems," DTMB Report 890, December 1954.

The problem of resonant whirling of propeller-shaft systems is discussed with special emphasis on those factors determining the critical speeds. Several methods for computing the natural whirling frequencies of propeller-shaft systems are presented and discussed. Computed and experimentally determined natural frequencies are compared.

Jasper, N.H., "Statistical Distribution Patterns of Ocean Waves and of Wave-Induced Ship Stresses and Motions, with Engineering Applications," DTMB Report 921, October 1957. Also published in SNAME Transactions, Vol. 64, 1956.

This research attempts to show that by utilization of statistical methods, it is possible to describe and predict service conditions for ships in an orderly and relatively simple manner despite the general complexities of the problem.

Wave-induced motions and stresses in ships obtained under a wide range of operating conditions are presented for seven different ships.

Kapiloff, E., "Calculation of Normal Modes and Natural Frequencies of Ship Hulls by Means of the Electrical Analog," DTMB Report 742, July 1954.

The electrical analog for the transverse vibration of a nonuniform beam with both shear and bending flexibility is reviewed to illustrate the general method of development of such a network. Inasmuch as the dynamics of transverse vibration of a nonuniform beam with shear and bending flexibility are those for the flexural vibration of a ship hull considered as a free continuous, nonuniform beam, the practical application of the analog is shown by presenting the normal modes of vibration of a naval vessel.

Kennard, E.H., "Forced Vibrations of Beams and the Effect of Sprung Masses," DTMB Report 955, July 1955.

Certain aspects of beam vibrations are discussed which throw light upon particular features of ship vibrations. These aspects are: antiresonances and effects of damping in forced vibrations, explicit formulas being given for uniform beams; internal versus external damping; effects of sprung masses on natural frequencies; and forcing functions resulting from sprung masses.

Leibowitz, Ralph C. and Kennard, E.H., "Theory of Freely Vibrating Nonuniform Beams, Including Methods of Solution and Application to Ships," DTMB Report 1317, May 1961.

A comprehensive study, which reviews and extends previous work, was made of the derivation of equations for digital and electrical-analog solutions of the natural frequencies and mode shapes of a ship's hull idealized as an elastic beam.

Effects of bending, shear, rotary inertia, coupled torsion and bending, initial curvature of the elastic axis, applied forces and torques, sprung masses, and other inertias are included. The calculation of the physical parameters from ship plans is described and the accuracy of results discussed.

Lewis, F.M., "Propeller Vibration," SNAME, Vol. 43, p.252, 1935.

In 1931 the Council of the SNAME appointed a committee to study the problem of propeller vibration. This paper covers the status of the problem and the work of the committee to date.

Lewis, F.M., "Propeller Vibration," SNAME, Vol. 44, p.50, 1936.

This paper is a report of work carried out by the vibration Research Committee of SNAME during 1936.

Lewis, F.M. and Tachmindji, A.J., "Propeller Forces Exciting Hull Vibration," SNAME, Vol. 62, p.397, 1954.

This paper deals with the work accomplished under the sponsorship of Panel H-8 of SNAME. It presents experimental results obtained from models, which include such effects as rpm, axial and tip propeller clearances. Experimental results obtained on full-scale vessels are compared with those obtained from model experiments and the laws of comparison are discussed.

Mathewson, Alice W., "Calculation of the Normal Vertical Flexural Modes of Hull Vibration by the Digital Process," DTMB Report 706, February 1960.

A method for the calculations of flexural frequencies and normal modes of ship hulls is presented. A comparison of experimental and computed natural frequencies are given for the USS NIAGARA (APA 87).

McGoldrick, R.T., "Buoyancy Effects on Natural Frequency of Vertical Modes of Hull Vibration," Journal of Ship Research, Vol. 1, No. 2, p. 47, July 1957.

This paper discusses the inertia and buoyancy effects on the vertical flexural modes of hull vibration. The inertia effects of the surrounding water is known to be very large and are always taken into account in calculating the natural frequencies of hulls; whereas, the buoyancy effects are invariably neglected. It is shown that buoyancy effect is negligible for vertical flexural modes except for ships with extremely low fundamental vertical frequencies.

McGoldrick, R.T. and Kane, J.R., "Longitudinal Vibrations of Marine Propulsion Shafting Systems," SNAME, Vol. 57, November 1949. Also DTMB Report 1088, November 1956.

This paper is intended to give methods to facilitate preliminary estimates of the longitudinal critical speeds based upon estimates of some of the system constants, and to indicate the process by which these estimated values may be calculated in more detail as detail drawings of foundations, thrust bearing mountings, propeller installations, etc., are made available.

McGoldrick, R.T., et al., "Recent Developments in the Theory of Ship Vibration," DTMB Report 739, October 1953.

It is shown in this report that by considering the ship hull as a floating beam having shearing and bending flexibility with a distributed viscous damping proportional to mass, it is possible to derive equations of motion under external forces by the general Rayleigh method which yields a solution in terms of normal modes of motion.

McGoldrick, R.T., "Ship Vibration," DTMB Report 1451, December 1960.

This report presents a general treatment of the subject of ship vibration, including both the structural and hydrodynamic phases, with suggested procedures for dealing with vibration problems in the ship's early design stage.

Noonan, E.F., "Mechanical Vibrations of Shipboard Equipment," MIL-STD-167 (SHIPS) December 1954.

This is the Bureau of Ships approved standard for vibration testing of shipboard equipment and machinery.

Noonan, E.F., "Tailshaft Bending Stresses on SS ESSO JAMESTOWN," American Society of Naval Engineers, Vol. 73, p.603, August 1961.

This paper presents part of the results obtained under the research program "Tailshaft Failures" by SNAME. The paper is comprised of the following sections:

- Section I, Background and Purpose
- Section II, Instrumentation and Calibration
- Section III, Test Results
- Section IV, Harmonic Analysis
- Section V, Phase Relationship
- Section VI, Comparison with Previous Tests
- Section VII, Comparison with Recommended Formulae
- Section VIII, Conclusions and Recommendations

Noonan, E.F., "Vibration Measurements on Ship S6-3 During Acceptance Trials," NKF Report 6010, June 1960, (Prepared for SNAME, Hull Structures Committee).

Various vibration test instruments are evaluated for probable adoption in the vibration code under development by SNAME. Various operating conditions are simultaneously studied for their influence on standard operating test procedure.

Noonan, Edward F. and Zaloumis, Angelos, "Shipboard Vibration and Noise Considerations in the Design of River Towboats," DTMB Report 1758, July 1963.

This paper reviews some of the problem areas which are of major importance to the naval architect in the design of river towboats and offers reasonable suggestions to be considered in the design of such vessels.

Panagopolos, E.P. and Nickerson, A.M., "Propeller Shaft Stresses Under Service Conditions," SNAME, Vol. 62, p.199, 1954.

This paper gives work accomplished under the SNAME, Ships' Machinery Committee Project NOS. M-8 and M-11 for improving the design of tailshaft and propeller shaft assemblies.

Polachek, H., "Calculation of Transient Excitation of Ship Hulls by Finite Difference Methods," DTMB Report 1120, July 1957.

A system of finite difference equations based on the nonuniform beam theory is presented for use in the calculation of the response of a ship hull to transient forces. The conditions for stability of these equations are derived. The feasibility of the method is tested by the solution of a vibration problem for a specific hull discussed in DTMB Report 1119.

Prohl, M.A., "A General Method for Calculating Critical Speeds of Flexible Rotors," Journal of Applied Mechanics, Vol. 12, No. 3, September 1945.

The actual rotor is simulated by a rotor in which the mass is concentrated at several equally spaced stations. The masses are considered to be connected by weightless flexural members.

Reed, F.E. and Bradshaw, R.T., "Ship Hull Vibrations; The Distribution of Exciting Forces Generated by Propellers," CONESCO Report No. F-101-2, June 1960.

This paper presents a practical method of computing the three components of force and the three components of moment on a propeller with the water-inertia effects included.

Ritger, P.D. and Breslin, J.P., "A Theory for the Quasi-Steady and Unsteady Thrust and Torque for a Propeller in a Ship Wake," Stevens Institute of Technology ETT Report 686, July 1958.

Unsteady aerodynamic theory is applied to problems of varying thrust and torque experienced by a marine propeller working in a non-uniform wake.

Russo, V.L. and McGoldrick, R.T., "Hull Vibration Investigation of SS GOPHER MARINER," SNAME Vol. 63, 1955. Also DTMB Report 1060, July 1956.

This report describes methods for determining influence coefficients for use with formulas developed at DTMB for computing the critical frequencies of whirling vibration of propeller shafting systems, and tabulates, for purpose of comparison, the computed and experimentally determined natural frequencies.

Tachmindji, A.J. and Dickerson, M.C., "The Measurements of Oscillating Pressures in the Vicinity of Propellers," DTMB Report 1130, April 1957.

Results are given for the oscillating pressures measured at points in the free-stream, both ahead and behind the propellers, and on an imaginary plane parallel to the propeller axis. The effect of rpm, propeller loading, and speed coefficient have been investigated. Results have been obtained for the effect of the number of blades. The oscillating pressure for a 4-bladed propeller has been calculated.

Tachmindji, A.J. and Dickerson, M.C., "The Measurement of Thrust Fluctuations and Free-Space Oscillating Pressures for a Propeller," DTMB Report 1107, January 1957.

This report gives the instrumentation and technique of measurement of the thrust fluctuations produced by a propeller when operating in a variable inflow field. It also describes the method of measurement of the oscillating pressure at a point in space in the vicinity of the screw. Representative results are given for a propeller operating in a series of similar wake distributions of varying magnitudes.

Taskonas, S., et al., "The Vibratory Force and Moment Produced by a Marine Propeller on a Long Rigid Strip," Stevens Institute of Technology, Davidson Laboratory Report 817, March 1962.

The blade-frequency forces and moments produced on a long flat plate of finite width by a propeller operating on a shaft parallel to the long axis of the plate are found in terms of simple algebraic formulas. The formulas allow evaluation of the influence of tip clearance, number of blades, thrust loading, advance ratio, and blade thickness.

2. SHIP STRUCTURES REPORTS

Abramson, H.N. and Chu, W.H., "Effects of the Free Surface on the Flutter of Submerged Hydrofoils," Journal of Ship Research, Vol. 3, No. 1, June 1959.

Expressions for the unsteady lift and moment acting on an oscillating hydrofoil submerged under a free surface are derived by an extension of classical unsteady thin-airfoil theory. The results of flutter computations are presented for a hypothetical example.

Abramson, H.N. and Chu, W.H., "A Discussion of the Flutter of Submerged Hydrofoils," Journal of Ship Research, Vol. 3, No. 2, October 1959.

This paper presents the results of a review and analysis of the problem of flutter of submerged surfaces. It is noted that certain rather serious discrepancies exist between theory and experiment leading to highly unconservative predictions of flutter speeds. A number of possible reasons for these discrepancies are investigated and discussed in detail.

Adams, Emily J., "The Steady-State Response of a Ship's Hull to a Simple Harmonic Driving Force Computed by a Digital Process," DTMB Report 715, 1959.

A numerical method of finding the steady-state response of the hull of a ship to a sinusoidal driving force is described. Results of calculations for the vertical flexural vibration of the USS NIAGARA (APA 87) are given and compared with experimental data. It is also shown that the vibration of the hull at a frequency other than one of the natural mode frequencies may be calculated as the sum of the vibrations of the natural modes compounded by a normalization process.

Adams, E.J., and Welch, A.R., "Calculation of Flexural Critical Frequencies of Ship Hulls by Prohl's Method," DTMB Report 552, July 1947.

This report extends Prohl's method for the calculation of the flexural critical frequencies of flexible rotors to the calculation of the flexural critical frequencies of ship hulls. The method is simplified and set up so that the computations can be readily made with a punch-card machine.

Albright, C.L., Jr., "Underway Hull Vibration Survey of USS MITSCHER (DL-2)," DTMB Report 1154, September 1957.

Hull vibrations measured at the bow and stern under various operating conditions were within tolerable limits. The hull exhibited vertical resonances at 69 and 140 cpm and athwartships resonances at 114 and 236 cpm. Some equipment vibrated excessively, such as the radar indicator for the Mk 67 director.

Albright, Clayton L., Jr., "Underway Hull Vibration Survey of USS PLYMOUTH ROCK (LSD-29)," DTMB Report 1029, May 1956.

Hull vibration measurements were made for various operating conditions. A maximum of 11 mils vertical vibration single amplitude was noted on the bow, and 42 mils on the stern. Hull vibration was within tolerable limits, and there was little vibration of shipboard equipment.

Allnutt, R.B., "Investigation of Hull Vibrations of USCGC PONTCHARTRAIN (WPG 70)," DTMB Report R-294, August 1946.

Because two rather severe critical series of vibrations were encountered during the trials of a recent class of U.S. Coast Guard vessels, vibrations produced in the PONTCHARTRAIN by a vibration generator were measured to determine the various critical frequencies of the hull. It is concluded that a 4- or 5-bladed propeller would reduce the hull vibration to acceptable levels.

Allnutt, Ralph B., "Vibration Survey of the USS CORAL SEA (CVB 43), Conducted During Ship Trials," DTMB Report C-268, October 1949.

This vibration survey was made to determine the vibration characteristics of the hull and machinery with different propellers and to determine the effect of various bottom paints on the inflow to the propellers and thereby effecting the ship's vibration. It was found that four-bladed propellers outboard and five inboard was the best arrangement, and that the effect of different bottom paints was negligible.

Anderson, R.A., and Houbalt, J.C., "Effects of Shear Lag on Bending Vibration of Box Beams," NACA TN 1583, May 1948.

Andrews, John N., "A Method for Computing the Response of a Ship to a Transient Force," DTMB Report 1544, November 1936.

A method for determining the elastic body response of a ship to a seaway is presented. The force generated by the seaway is considered to consist of two parts, i.e., an unsteady hydrodynamic force obtained from the measured rigid body motions, and a hydrostatic force. The force and mass-elastic parameters representing the hull are used as input quantities on a digital computer to obtain the ship's response.

Baier, L.A. and Ormondroyd, J., "Suppression of Ship Vibration by Flow Control," Third Mid-Western Conference on Fluid Mechanics, 1953.

Baier, L.A. and Ormondroyd, J., "Vibration at the Stern of Single Screw Vessels," Trans SNAME, Vol. 60, p.10, 1952.

This paper discusses means used to reduce the stern vibration on Great Lakes bulk carriers.

Bales, Nathan K., "A Method for Predicting the Probable Number and Severity of Collisions between Foil-borne Craft and Floating Debris," DTMB Report 1723, August 1963.

This report derives a method for predicting the approximate number of collisions producing a structural response of given severity to be anticipated over a long operating period. The derivation is based on certain assumed debris item frequency distributions.

Bales, N.K., "The Ordinary Wave-Induced Responses of a Victory Cargo Ship," DTMB Report 1734, December 1963.

The ordinary wave-induced midship vertical bending stress and pitching, rolling, and heaving motions of a Victory cargo ship are presented. Short-term, long-term, and maximum-value statistical analyses are described.

Birmingham, J.T., et. al., "Statistical Presentation of Motions and Hull Bending Moments of Destroyers," DTMB Report 1198, 1960.

The motions and the longitudinal hull bending moments that a destroyer of the DD 692 Class is expected to experience over a wide range of operating conditions are presented in statistical form. Criteria are derived for use in design and operational problems.

Birmingham, J.T. and McGoldrick, R.T., "Vibration Generator Experiments on SS GOPHER MARINER," DTMB Report 1011, March 1956.

Results obtained during excitation by a mechanical vibration generator of the SS GOPHER MARINER under two different conditions of loading are presented in this report. Observations are made on the experimental techniques, with suggestions for improvements in future investigations.

Bisplinghoff, R.L., "Method of Determining Natural Modes and Frequencies for Transverse Vibrations of Beams," Department of Aeronautical Engineering, MIT, ONR Contract N5-ori-07833, ONR Project NR-064-259, 1952.

Bleich, H.H., "Nonlinear Distribution of Bending Stresses Due to Distortion of Cross Section," Transactions of American Society of Mechanical Engineers, Paper No. 52, 1952.

Breslin, J.P., "A Theory of the Vibratory Effects Produced by a Propeller on a Large Plate," Journal of Ship Research, Vol. 3, No. 3, 1959.

The flow generated on an infinite plane by a single-bladed propeller rotating on a shaft parallel to the plane in a uniform inflow is first considered. The vibratory forces of this system and multibladed systems are discussed for conditions of uniform and nonuniform inflow.

Breslin, J.P., "The Pressure Field near a Ship Propeller," Journal of Ship Research, Vol. 1, No. 4, March 1958.

A brief summary is given of efforts in the field of naval architecture on the problem of determining the vibratory forces and moments produced by a ship propeller, and an account of the principle contribution made by aeronautical researchers on the problem of computing the fluctuating pressure field near a propeller. Some characteristics of the pressure field are discussed briefly.

Breslin, J.P., "The Unsteady Pressure Field near a Ship Propeller and the Nature of the Vibratory Forces Produced on an Adjacent Surface," Stevens Institute of Technology, ETT Report 609, 1956.

Forces on a flat plate were calculated in a uniform flow when a single-line vortex passed the plate. The calculations were for the two-dimensional problem. Results show that clearances behind the vortex are not as important as clearances ahead of the vortex, or clearances between hull and propeller are more significant than those between propeller and rudder.

Breslin, J.P., "Ship Vibration, Part I - Propeller-Generated Excitations," Applied Mechanics Review, Vol. 13, No. 7, 1960.

This paper presents a study of the blade-frequency pressure and velocity field near ship propellers, the forces that induce vibration of nearby surfaces and structures, and the cyclic variations of the thrust and torque developed by propellers operating in a variable flow field at the stem of ships.

Breslin, J.P. and Tsakonas, S., "Marine Propeller Pressure Field due to Loading and Thickness Effects," Stevens Institute of Technology, ETT, Note No. 518, 1959. Also Trans. SNAME, Vol. 67, 1959.

This paper presents the blade-frequency pressure field of a propeller as a function of torque and thrust loading, and blade thickness effects. The latter had not been accounted for previously. Theoretical results are compared to experimental results.

Breslin, J.P. and Tsakonas, S., "The Blade Frequency Velocity Field near an Operating Marine Propeller Due to Loading and Thickness Effects," Sixth Annual Conference on Fluid Mechanics, University of Texas, 1959.

The velocity fluctuations due to loading and blade thickness effects at any point in the vicinity of a propeller operating in open water conditions in an incompressible ideal fluid are determined. Broad conclusions are drawn as to the relative magnitudes of the contributions of each of the elements to the various velocity components. The blade thickness effect on the pressure and velocity fields is shown to be of primary importance.

Buchmann, E., "Calculated and Measured Vibration on a Newly Designed Ship," Symposium on Vibration, Instrument Society of America and Society for Experimental Stress Analysis, 1961.

The use of higher horsepower engines requires a careful evaluation of vibratory levels on ships. This presentation covers the calculation of ship vibration, the measurement of hull vibratory characteristics and the analysis and presentation of data as used at the David Taylor Model Basin.

Buchmann, E., "Criteria for Human Reaction to Environmental Vibration on Naval Ships," Institute for Environmental Science, 1962. Also DTMB Report 1635, June 1962.

The results of an extensive research of existing literature on human reactions to vibration, are presented. Vibration norms for human reaction to vibration are suggested.

Buchmann, Erich, "Ship Vibration," Institute of Environmental Science, 1961.

Knowledge of ship vibration during any operation and in any sea condition is necessary for the designer of shipboard equipment. Vibration levels are discussed for two classes of Navy ships, the 692 Class destroyer and the ESSEX Class carrier.

Buchmann, Erich, "Vibration Measurements on Vessel S6-1 during Acceptance Trials," DTMB Report 1297, February 1959, (Distributed only upon authorization of SNAME, Hull Structures Committee.)

Underway vibration test on passenger-cargo ship was conducted. Test data were used to evaluate the stability of DTMB two-component pallograph.

Buchmann, E. and Birmingham, J.T., "Vibration Survey on U.S. Army Ship LT COL JOHN U.D. PAGE (BDL-IX)," DTMB Report 1343, June 1959.

A vibration survey was conducted on this ship to ascertain the cause of excessive vibration of bulkheads bounding the aft ballast tanks in the area of the shaft alley.

Buchmann, E. and Jasper, N.H., "Vibration Measurements on Port Propulsion System of USNS POINT BARROW (T-AKD-1)," DTMB Report 1286, December 1958.

Vibrations were measured to determine the cause of an engine casualty. Large torque variations of the propeller shaft occurred at very low rpm and generated thrust variation. These vibrations are probably self-excited by large binding forces at the shaft bearings. Vibration resonances at turbine and double-turbine frequencies occurred at the turbine housing at about 140 shaft rpm and are probably excited by unbalance in the turbine system.

Buchmann, E. and McConnel, J.D., "Environmental Conditions of Ship Motions and Vibrations for Design of Radar Systems on Destroyers and Aircraft Carriers," DTMB Report 1298, 1959.

Rigid-body motions and vibrations measured over a long period of time and a wide range of operating conditions are used to determine the environmental conditions of vibration and ship motion for use in the design of radar installations. Extreme values for ship motions in severe seas are predicted. Application of the data to design problems are discussed.

Buckingham, E., "Model Experiments and the Forms of Empirical Equations," Trans ASME, Vol. 37, 1915.

Chuang, Sheng-Lun, "The TMB Flexing Stress Monitor," DTMB Report 1560, February 1962.

A Flexing Stress Monitor has been developed to measure the strains and to compute, record, and display the associated stresses experienced by a ship at sea. The continuous records are suitable for statistical analysis at a later date to provide general information of use in ship design.

Church, J.W. and Andrews, J.N., "A Model for the Simulation of the Transient Vibration Resulting from Wave Impact Loads on a Naval Vessel," Presented at Shock and Vibration Colloquium, Annual Meeting ASME, November 1963.

A structural model of an aircraft carrier has been designed and constructed in order to study the transient vibratory response of the ship to impact-type wave loads. Tests will be conducted at various speeds in regular and irregular seas. Test objectives are to establish the validity of model simulation techniques through comparison with full-scale results and to provide data for evaluation of analog computer procedures.

Corbett, J.P., "Summary of Transformations Useful in Constructing Analogs of Linear Vibration Problems," MEE Trans, Vol. 68, 1949.

This paper is concerned with the problem of representing linear vibration systems in terms of electric circuits. The system under study is represented by linear differential equations with constant coefficients.

Crawford, Lyndon and Ruby, William J., "Model Tests on Hull-Dockhouse Interaction," BuShips Project NS-731-1034, Final Report Project No. SR 121, SSC 67, 1955.

Crawford, Lyndon, "Theory of Long Ships' Superstructures," SNAME Trans, Vol. 58, p.693, 1950.

The apparent tendency of fundamental hull stresses to be attenuated in the superstructure of passenger ships has been verified by model tests. This action seems to result from the lack of a sufficient number of solid supports for the longitudinal load carrying members. Means for providing greater structural efficiencies for superstructures are apparently available, which promise economies in steel hull weight.

Criner, E., et al., "A New Device for the Solution of Transient Vibration Problems by the Method of Electrical-Mechanical Analogy," Journal of Applied Mechanics, 1945.

Crook, Mary C., "Summary of Reports on Vibration Surveys Issued during 1959," DTMB Report 1402, January 1960.

This report contains a listing of DTMB Vibration Survey Reports issued in 1959 and Dr. N.H. Jasper's comments on vibration tests conducted on the USS SKIPJACK (SSN 585).

Crumb, S.F., "A Study of the Effects of Damping on Normal Modes of Electrical and Mechanical Systems," California Institute of Technology, Tech Report 2, Air Research and Development Command, Office of Scientific Research, Contract AF 18(600)-669, Project R-354-30-1, 1955.

Cummings, John T., "Calculated Natural Vertical Hull Frequencies and Normal Modes of Surveying Ship AGS 26," DTMB Report 1704, March 1963.

The normal mode shapes, natural frequencies and bending moment distributions of flexural vibration of the hull were calculated. The parameters used in calculations with a digital computer are tabulated.

Cummings, John T., "Vibration of Radar Mast Measured on USS LONG BEACH (CGN 9) and USS OKINAWA (LPH 3)," DTMB Report 1789, December 1963.

Maximum amplitudes and accelerations measured on the radar mast of USS OKINAWA (LPH 3) and USS LONG BEACH (CGN 9), are presented. Amplitudes and acceleration due both to propeller-blade and shaft frequencies and to maneuvers are included.

Davenport, W.W., et al., "A Substitute-Stringer Approach for Including Shear-Lag Effects in Box-Beam Vibrations," NACA TN 3158, 1954.

The use of the substitute-stringer approach for including shear lag in the calculation of transverse modes and frequencies of box beams is discussed. Various thin-walled hollow rectangular beams of uniform wall thickness are idealized by means of the substitute-stringer approach and the resulting frequencies of the idealized structures are compared with those of the original beams. The results indicate how the idealization could be made in order to yield accurate representation of the shear-lag effect in dynamic analysis.

Davidson, Samuel, "Vibration Measurements Made 11 July 1947 on USS ODAX (SS 484)," DTMB Report C-3, August 1947. (Declassified).

Certain vibrations were recorded which, it is believed, were due primarily to a stabilizer which was mounted near the after section of the propeller shaft. After the stabilizer was cut back from the propellers, vibration measurements showed a significant decrease in the level of vibration.

Davidson, Samuel, "Vibration Measurements Made in August 1947 on the USS AMBERJACK (SS 522)," DTMB Report C-34, November 1947. (Declassified.)

Vibration measurements revealed low levels of vibration at blade frequency throughout the operating speed range. Comparison with the results of tests on the ODAX which has stabilizing planes mounted near the propeller and higher levels of vibration indicates that the hydrodynamic action between the propeller and stabilizing planes contributes significantly to the vibration.

Don Hartog, J.P., "Use of Models in Vibration Research," ASME Trans, Vol. 54, 1932.

Dolph, C.L., "Normal Modes of Oscillation of Beams," External Memorandum UMM-79, University of Michigan Research Institute, 1951.

Dutton, G.Wayne and Leibowitz, Ralph C., "A Procedure for Determining the Virtual Mass J-Factors for the Flexural Modes of a Vibrating Beam," DTMB Report 1623, August 1962.

This report presents a procedure for calculating the virtual mass of a ship by using different J-factors for each mode of vibration. Comparison between theoretical and experimental frequencies for SS E.J. KULAS indicates that better agreement is obtained up through the fifth mode for the light condition and up through the fourth mode for the loaded condition.

Feldman S., "Dynamic Balancing for Noise Reduction," Department of Navy, Bureau of Ships (Code 371) R & D Report 371-V-24, April 1955.

This report covers a study of the effects of rotor unbalance on the first order structureborne noise of several items of submarine auxiliary machinery. It is shown that a point of diminishing returns exists for balancing the rotor, and that the four balancing machines used in this study can balance rotors beyond this point. Recommendations are made for the establishment of tolerances of unbalance for submarine auxiliary machinery.

Flax, A.H., "Aero-Hydro-Elasticity," Structural Mechanics, Proceeding of First Symposium on Navy Structural Mechanics, Pergamon Press, New York, 1960.

Fontaine, William R., "Calculated Natural Frequencies, Normal Modes of Vibration, and Response of the Hull of AGSS 555," DTMB Report 1615, June 1962.

Normal mode shapes and natural frequencies of flexural vibration of the hull and of longitudinal vibration of the hull-propulsion system were calculated for AGSS 555. The effect of different estimated spring constants, coupling the propulsion system to an infinitely stiff hull and to a flexible hull, on longitudinal mode shapes and natural frequencies was determined. Parameters used in the calculations are given.

Fontaine, William R., "Calculated Natural Frequencies, Normal Modes, and Longitudinal Responses of MST-12 Counter-Rotating Propulsion System and Coupled Hull of USS JACK (SSN 605)," DTMB Report 1655, October 1962.

Normal mode shapes and natural frequencies of vertical flexural vibration of the hull and of longitudinal vibration of the hull-propulsion system were calculated. The forced response and the effect of thrust bearing foundation stiffness are also considered.

Fontaine, W.R., "Calculated Natural Frequencies, Normal Modes, and Forced Response of Hull and Propulsion System of USS SKIPJACK (SSN 585)," DTMB Report 1756, August 1963.

Natural frequencies, mode shapes, and the forced response of the hull in its vertical mode and of the hull-propulsion system in its longitudinal mode are calculated.

Gariboldi, R.J., "Procedure for Torsional Vibration Analysis of Multimass Systems," Department of Navy, Bureau of Ships (Code 371), R & D Report 371-V-19, December 1953.

This report presents a systematic procedure for the analysis of torsional vibration of multimass systems. It includes a detailed numerical analysis of a diesel propulsion system as an example.

Gesswein, Barbara H. and Moses, Fred, "Calculated Modes and Frequencies of Hull Vibration of USS GEORGE WASHINGTON (SSBN 598)," DTMB Report 1464, November 1960.

Normal mode shapes, natural frequencies, and bending moments of vertical flexural vibration and of longitudinal vibration of the hull and of the shafting system were calculated for USS GEORGE WASHINGTON (SSBN 598). The methods used in evaluating the parameters are discussed.

Getz, Jan R., "Longitudinal Strength and Minimum Weight," DTMB Report 1649, December 1962.

The danger of brittle fracture, fatigue, and the importance of built in or thermal stresses are discussed. The longitudinal stresses are based on statistical measurements and calculations with an economy-based risk of damage or need for change of speed and course. The danger of complete structural failure is discussed. Measurements from ships are compared with oceanographical data and statistical calculations based on them.

Gold, P.D. et al, "Vibration Engineering—Resume of Applications to Solutions of Marine Operational Problems Encountered by Naval Vessels," Trans SNAME, Vol. 61, 1953.

This paper presents a summary of the methods developed and used by Boston Naval Shipyard to resolve vibration and noise problems encountered during the operation of naval vessels.

Goldman, D.E., "A Review of Subjective Responses to Vibratory Motion of the Human Body in the Frequency Range 1-70 Cycles Per Second," Project N.M. 004-001, Report No. 1, Naval Medical Research Institute, 1948.

Goldman, D., et al., "The Biological Effects of Vibration," Report of Working Group 39, Armed Forces National Research Council on Hearing and Bio-Acoustics, April 1961.

Goldman, D. and Gierke, H., "The Effects of Shock and Vibration on Man," Lecture and Review Series No. 60-3, Naval Medical Research Institute, January 1960.

Greenspon, J.E., "A Shell Type Approach for the Vibration and Acoustic Analysis of Ship and Submarine Hulls," DTMB Contract No. Nonr-2862-(00)X. Technical Report No. 1, May 1960.

A study was initiated in an attempt to derive a shell type approach for the vibration of surface ship and submarine hulls. This report comprises a feasibility study on such an approach.

Greenspon, J.E., "Sea Tests of the USCGC UNIMAK, Part 3--Pressures, Strains, and Deflections of the Bottom Plating Incident to Slamming," DTMB Report 978, March 1956.

This report presents and discusses some of the test data taken during rough-water sea trials of a Coast Guard cutter on weather patrol duty. The data includes the impact pressures incident to slamming as well as the corresponding strains and deflections of the forward bottom plating. These measurements are compared with results obtained from theoretical considerations.

Greenspon, J.E. and Wigle, B.M., "Probability Distribution of Wave-Induced Hull Girder Stresses for a Destroyer Escort, Based on Sea Tests of USS FRESSENDEN (DER-142)," DTMB Report 1020, April 1956.

Gives hull stress distributions for rough weather service off DER-142 off the North Atlantic coast.

Greenwood, D.T., "Analog Methods of Non-Linear Vibration Analysis," Thesis, California Institute of Technology, 1951.

Hardy, V.S., "Vibration Measurements Made on the USS PHILIPPINE SEA (CV 47) during Standardization Trials of 5 June to 1 July 1947," DTMB Report C-6, August 1947. (Declassified.)

The purpose of these vibration measurements was to determine the relative effect of four-bladed CLYBEN and NACABS propellers on the vibration of the vessel. Vibration amplitudes were small with both types of propellers but NACABS gave slightly less vibration below 240 rpm.

Hardy, V.S., "Vibration Studies of Ship Hulls by Means of Vibration Generators," DTMB Report C-80, 1949. (Declassified.)

This report gives a summary of the vibration-generator tests conducted by DTMB prior to 1949. The experimental natural frequencies are compared with corresponding frequencies computed by using Schlick's and Burrell's empirical formulas.

Hardy, Virgil S. and Jasper, Norman H., "Vibration and Noise Tests of Timken Trunnion Roller Bearings on LSM 297," DTMB Report C-149, December 1948.

The vibration and noise characteristics of Timken trunnion bearings and of standard sleeve-type bearings were determined during a test of both installed on the LSM 297. The vibration tests showed the present design of the trunnion bearing to be unsatisfactory, and recommendations for redesign of its rubber mounting are made. Differences in airborne noise from the two types are insignificant.

Hayman, Dr.F., "A Method of Evaluating the Hydraulic Vibration Reducer by an Electrical Analog," DTMB Report 1616, June 1962.

This report presents a method for evaluating the parameters of a hydraulic vibration reducer by an electrical mobility analog. The conversion of the hydraulic properties of the vibration reducer into an equivalent mechanical system is detailed in an appendix.

Harrison, M., et al., "Wave Effects in Isolation Mounts," DTMB Report 766, January 1952.

Both theoretical and experimental studies of wave effects in isolation mounts have been made. The well-known 'lumped parameter' theory of vibration mounts holds true only when the wavelength of the elastic wave in the mount is large compared to the dimensions of the mount. Standing waves occur which in certain frequency ranges decrease the vibration isolation properties of the mount by as much as 20 db. The theoretical and experimental treatments are in good agreement, and indicate various methods for improving the vibration isolation properties of the mount.

Hayes, Wallace D., "Effective Mass of a Deformable Circular Cylinder," Graduate Division of Applied Mathematics, Brown University, ONR Contract N7onr-35810, Tech Report 1, August 1951.

The concept of the effective mass tensor is extended to apply to the problem of hydrodynamic forces acting on a deformable body. The concept is illustrated by an example.

Heller, S.R., "Natural Frequencies of Shaft Struts," DTMB Report 1219, April 1958.

Shaft strut vibration tests were made on several carriers and certain apparent inconsistencies in the results indicated the desirability of developing an analytic solution for the problem which might explain the inconsistencies. This paper presents an analytic solution.

Heller, S.R., Jr., "Wave Geometry for Longitudinal Strength," Transactions of American Society of Naval Engineers, 1954.

This paper has the following threefold purpose:
1. Portray the historical development of standard longitudinal strength calculations,
2. Show the inconsistencies in these calculations,
3. Suggest means to remedy the inconsistencies.

Heller, S.R., Jr. and Abramson, H.N., "Hydroelasticity: A New Naval Science," Journal ASNE, May 1959.

Many of the various subjects which comprise aeroelasticity have the counterparts in the field of naval architecture. In an effort to provide a framework for hydroelasticity, these counterparts are defined and discussed.

Hermann, G., "Forced Motions of Timoshenko Beams," Contract Nonr-266(09), Columbia University Tech Report No. 9, June 1953.

Timoshenko's theory of flexural motions in an elastic beam takes into account both rotatory inertia and transverse shear deformation and accordingly, contains two dependent variables instead of the one transverse displacement of classical theory of flexure. For the case of forced motions, the solution involves complications not usually encountered. The difficulties may be surmounted in several ways. The method described here makes use of the property of orthogonality of the principle modes of free vibration and uses the procedure of Mindlin and Goodman in dealing with the time-dependent boundary conditions. Thus, the most general problem of forced motion is reduced to a free vibration problem and a quadrature.

Hermes, R.M., "Dynamic Modeling for Stress Similitude," Contract N8 onr-523, Department of Applied Mechanics, University of Santa Clara, Santa Clara, Calif., June 1949.

A method of rendering the equations of motion of a vibrating beam in dimensionless form is presented. The parameters, which must be kept constant for modeling for dynamic stress similitude are derived from the foregoing dimensionless equations of motion. Internal damping is considered and the conclusion is reached that it can be satisfactorily modeled.

Howe, C.E., and Howe, R.M., "Application of the Electronic Differential Analyzer to the Oscillation of Beams, Including Shear and Rotary Inertia," ASME, Applied Mechanics Division, September 1953.

Jasper, N.H., "A Design Approach to the Problem of Critical Whirling Speeds of Shaft-Disk Systems," DTMB Report 890, December 1954.

Several methods for computing the natural whirling frequencies of propeller-shaft systems are presented and discussed. Computed and experimentally determined natural frequencies are compared.

Jasper, Norman H., "A Theoretical and Experimental Study of Propeller-Shaft Failures," DTMB Report 808, August 1953.

This report presents a detailed study of the stresses in the tailshaft of a T2-SE-A2 tanker of the MISSION type, including an analysis of the causes of tailshaft failure encountered in these as well as in Liberty ships and other ships of similar type. Emphasis is placed on the effects of a whirling type of flexural vibration on the stresses and motions of the shaft. One of the principal conclusions is that the shaft failures are due to a lack of endurance strength of the shaft as designed and built, and not due to a serious lack of endurance strength of the shafting material itself.

Jasper, N.H., "A Theoretical Approach to the Problem of Critical Whirling Speeds of Shaft-Disk Systems," DTMB Report 827, December 1954.

In this report a number of theoretical methods are derived for computing the natural frequencies of whirling vibration of shaft-disk systems including the consideration rotary inertia, gyroscopic precession, and flexibility of shaft supports, as well as lumped and distributed masses.

Jasper, N.H., "Dynamic Loading of a Motor Torpedo Boat (YP-110) during High-Speed Operation in Rough Water," DTMB Report C-175, September 1949. (Declassified)

Vibrational acceleration, stress, and hull pressure measurements are given for YP-110.

Jasper, N.H., "Service Stresses and Motions of the ESSO ASHEVILLE, a T-2 Tanker, Including a Statistical Analysis of Experimental Data," DTMB Report 960, September 1955.

Stresses amidships as well as pitching and heaving accelerations were measured. Analysis indicates that the dynamic stress variations associated with the ship's motion in waves will rarely exceed 12,000 psi peak-to-peak. The maximum stress variation due to changes in temperature (excluding stress concentrations) was about 11,000 psi.

Jasper, N.H., "Statistical Approach to Longitudinal Strength Design of Ships," American Society of Naval Engineers, pp 565-573, August 1950.

This paper examines the present status of the problem of 'Longitudinal strength of ships,' and presents a program of study of the strength requirements.

Jasper, N.H., "Statistical Distribution Patterns of Ocean Waves and of Wave-Induced Ship Stresses and Motions, with Engineering Applications," Trans. SNAME, Vol. 64, 1956. Also DTMB Report 921, October 1957.

This research attempts to show that by utilization of statistical methods, it is possible to describe and predict service conditions for ships in an orderly and relatively simple manner despite the general complexities of the problem. Wave-induced motions and stresses in ships obtained under a wide range of operating conditions are presented for seven different ships.

Jasper, N.H., "Structural Vibration Problems of Ships—A Study of the DD692 Class of Destroyers," DTMB Report C-36, February 1960. (Declassified)

An investigation was made to determine the sensitivity of this class to first order unbalanced forces. The long light hull was found to be lacking in torsional and flexural rigidity compared to other ship types. It was recommended that diagonal stiffeners be installed in the hull girder and that the specifications for straightness and balance of shafting be revised.

Jasper, N.H., "Vibration Generator Survey of the USS NIAGARA," DTMB Report 699, 1949.

Five modes of vertical vibration, three athwartship, and one torsional were determined by using a vibration generator. The experimental natural frequencies were compared with calculated values. Values of damping are calculated based on the experimental data.

Jasper, Norman H., "Vibration Measurements Made 11 August 1948 on the USS ODAX (SS 484)," DTMB Report C-170, January 1949. (Declassified)

Underway vibrations are given for both surfaced and submerged conditions of SS 484, also vibration measurements recorded during time that ship was excited by firing water slugs from Torpedo Tube No. 7.

Jasper, N.H., "Vibration Survey of the USS MIDWAY (CVB 41) Conducted during Ship Trials of July and August 1947," DTMB Report 690, March 1948.

A vibration survey was made to determine the ship's vibration characteristics with three- and four-bladed propellers. Three-bladed propellers were better as far as machinery vibration was concerned and four were better for hull vibration. The vibration of the outboard propulsion units was acceptable under both conditions, so the author recommends the three-bladed propellers for the inboard shafts, and four on the outboard shafts.

Jasper, Norman H. and Andrews, John N., "Preliminary Report of Strains and Motions of USS RANGER (CVA 61) during a Voyage around Cape Horn," DTMB Report 1289, January 1959.

Hull-bending stresses forward and amidships, local stresses around a large side opening, shear stresses in the shell plating forward, linear and angular ship motions are reported for conditions free of slamming as well as during a mild slam. It is concluded that the flight deck sponson makes a partial contribution to hull-girder strength and that slamming stresses contribute appreciably to the stress level.

Jasper, N.H. and Chruch, J.W., "Structural Seaworthiness Studies," Presented at Spring Meeting, SNAME, April 1963.

This paper gives a summarization of structural seaworthiness studies under dynamic loads conducted since 1950 with emphasis on the results of full-scale sea tests.

Jasper, Norman H. and Birmingham, John T., "Sea Tests of the USCGC UNIMAK, Part 1 - General Outline of Tests and Test Results," DTMB Report 976, March 1956.

Measurements of ship motions, hull girder stresses, bottom pressures, stresses in the bottom structure incident to slamming and stereophotographs of the sea were obtained under a wide variety of sea conditions, ship speeds, and headings relative to the waves. This report outlines the scope of the tests and presents the data in some detail.

Jasper, N.H. and Birmingham, J.T., "Strains and Motions of USS ESSEX (CVA 9) during Storms near Cape Horn," DTMB Report 1216, August 1958.

Strains, ship motions, and wave heights were measured on the ESSEX in very rough seas. The results, together with the damage to the TICONDEROGA under similar conditions, indicate inadequate buckling strength in parts of the hanger deck. When the bow flare is immersed, the large hydrodynamic forces involved cause a vertical whipping and high stresses. The report recommends strengthening the main deck longitudinally and considering whipping stresses in design.

Jasper, N.H. and Brooks, R.L., "Sea Tests of the USCGC UNIMAK, Part 2 - Statistical Presentation of the Motions, Hull Bending Moments, and Slamming Pressures for Ships of the AVP Type," DTMB Report 977, April 1957.

Based on extensive measurements, the motions and hull-girder bending moments which a ship similar to the UNIMAK may be expected to experience over a wide range of operating conditions are presented in statistical form. Formulas are given for use in estimating probable maximum values of moments and motions.

Jasper, N.H., Brooks, R.L., and Birmingham, J.T., Statistical Presentation of Motions and Hull Bending Moments of ESSEX-Class Aircraft Carriers," Revised Edition, DTMB Report 1251, June 1960.

The motions and longitudinal hull bending moments which ships of the ESSEX Class may be expected to experience over a wide range of operating conditions are presented in statistical form, based on extensive measurements on VALLEY FORGE and ESSEX. Formulas are given for use in estimating probable extreme values of moments and motions.

Jasper, N.H. and Rupp, L.A., "An Experimental and Theoretical Investigation of Propeller Shaft Failures," Trans. SNAME, 1952.

As a result of the high incidence of tail shaft failures the investigation reported here was undertaken. Tests of a tanker and theoretical considerations lead the authors to make specific recommendations in design procedure, operating procedure, and future research.

Jasper, N.H. and Wigle, D.M., "Motions of the SS SILVER MARINER in a State 5 Sea," DTMB Report 1067, October 1956.

Tests were made to determine the roll, pitch, and heave motions that this type vessel would experience in a State 5 sea for various speeds and headings. The largest values of motion during the tests are given, as well as the probabilities of exceeding a given magnitude of ship motion for various combinations of speed and heading.

Kane, J.R. and McGoldrick, R.T., "Longitudinal Vibrations of Marine Propulsion-Shafting Systems," Trans. SNAME, vol. 57, 1949. Also DTMB Report 1088, November 1956.

This paper shows that by a systematic analysis of the longitudinal mass-elastic system of a propulsion system, it is often possible to adjust the critical frequencies or select the number of blades for the propeller so as to minimize the effects of resonance. Also blade clearance, appendage design, and thrust bearing foundation effects are considered as factors to be considered in design.

Kapiloff, E., "Calculation of Normal Modes and Natural Frequencies of Ship Hulls by Means of the Electrical Analog," DTMB Report 742, July 1954.

The electrical analog for the transverse vibration of a nonuniform beam with both shear and bending flexibility is reviewed to illustrate the general method of development of such a network. Inasmuch as the dynamics of transverse vibration of a nonuniform beam with shear and bending flexibility are those for the flexural vibration of a ship hull considered as a free continuous, nonuniform beam, the practical application of the analog is shown by presenting the normal modes of vibration of a naval vessel.

Kapiloff, E. and Birmingham, J.T., "A Report on Hull Vibration Measurements Made on the SS BETHLEHEM and Vibration Generator Tests Made on the SSCA PAUL and the SS PERE MARQUETTE 21 while in service on the Great Lakes," DTMB Report 848, March 1953.

As part of the general program of extension of hull vibration theory to all classes of ships, this report describes tests made on three Great Lakes vessels and compares the experimental results with the computed values made according to the methods presently considered to be most satisfactory.

Kaplan, P., "A Study of the Virtual Mass Associated with the Vertical Vibration of Ships in Water," SIT, Davidson Laboratory, Report 734, December 1959.

A survey of the available theoretical and experimental studies related to the virtual mass of bodies vibrating on the free surface of water is presented. Comparison of theoretical and experimental results shows disagreement, the theoretical values being greater. This leads to errors in the calculation of the natural frequencies of vibration of ships. The effects of gravity wave formation, compressibility, viscosity, wall effects, and other physical mechanisms usually neglected are considered. Their influence does not improve the agreement.

Kennard, E.H., "Forced Vibrations of Beams and the Effect of Sprung Masses," DTMB Report 955, July 1955.

Certain aspects of beam vibrations are discussed which throw light upon particular features of ship vibration. These aspects are: Antiresonances and effects of damping in forced vibrations, explicit formulas being given for uniform beams; internal versus external damping; effects of sprung masses on natural frequencies; and forcing functions resulting from sprung masses.

Kennard, E.H., "Some Cases of Vibration Forced by Base Motions or by External Forces," DTMB Report 1394, December 1960.

This report gives formulas for the response of selected simple vibratory systems to either forced motions of their supports or to external forces. The systems treated include a sprung mass, a sprung rotor, a cantilever beam, and a general elastic system attached to a rigid base.

Kennard, E.H. and Leibowitz, R.C., "Theory of Rudder-Diving-Plane Ship Vibration and Flutter Including Methods of Solution - Part I," DTMB Report 1507, February 1962.

The purpose of this report is to more adequately represent a ship and its appendages as a mass-hydroelastic system, including sprung bodies, and devise solutions for natural frequencies, mode shapes, critical flutter speeds, and damping of this system, using analytical, digital, or electrical-analog methods.

Kenny, J.H. and Leibowitz, R.C., "Design Details and Operating Procedure for the DTMB Network Analyzer," DTMB Report 1272, April 1959.

This report describes the physical characteristics, components and instrumentation of the TMB Network Analyzer, and gives the layout arrangement and some construction details. The procedure for setup, calibration, and operation of the network analyzer is explained sufficiently to permit the reader to utilize the facility.

Kinsey, Carrol H., "Underway Vibration Survey of the Hull and Propulsion System of the USS DEALEY (DE 1006)," DTMB Report 950, August 1955.

Records of vertical and athwartships vibration were obtained at the bow and at the stern, and of fore-and-aft vibration at the thrust bearing and reduction gear housings.

Kinsey, C.H., "Vibration and Stresses Measured on Struts of USS SARATOGA (CVA 60)," DTMB Report 1133, July 1957.

The natural frequencies in air of the shaft struts were determined by impact testing. Vibration and strain measurements on the main strut of the starboard inboard shaft during vibration generator tests in air and water and during underway trials showed a resonance in water at 132 rpm, and that vibration and strain were within tolerable limits.

Kinsey, C.H., "Vibration Characteristics of Main Propulsion Unit in USS GUAVINA (AGSS 362)," DTMB Report 1168, October 1957.

Resonant frequencies and amplitudes of vibration of the resiliently mounted bedplate of the main propulsion unit were determined on GUAVINA during vibration-generator tests at dockside, during underway tests, and during vibration-generator tests with the submarine submerged.

Kinsey, Carrol H., "Vibration-Generator Tests on the After Superstructure of Certain Vessels of the LST 1156 Class," DTMB Report 928, December 1954.

Tests were made on two LSTs after completion of structural modifications to reduce the vibration of No. 3, Mk 63 gun directors. Most of the natural frequencies are above propeller blade frequencies.

Kinsey, Carrol H., "Vibration-Generator Tests of Main Thrust-Bearing Foundations on USS FORRESTAL (CVA 59)," DTMB Report 954, March 1955.

A vibration-generator test was conducted on the starboard main thrust bearings and their foundations aboard the USS FORRESTAL, while the shafting was disconnected on both sides of the thrust bearings, to determine experimentally the lowest resonance frequencies of these systems with the aim of estimating the longitudinal spring constants of the foundations, which were calculated to be 8.2×10^6 lb/in. and 8.9×10^5 lb/in.

Kron, G., "A Method of Solving Very Large Physical Systems in Easy Stages," Proceedings of IRE, April 1954.

Physical systems with a very large number of variables (say thousands) may be solved with digital computers by tearing the system apart into a large number of small subdivisions. After solving each subdivision, the partial solutions are interconnected by a set of transformations so as to obtain the exact solution of the original system. This paper illustrates the solution of Maxwell two-dimensional field-equations by tearing their electric-circuit models apart into a convenient number of subdivisions.

Kron, G., "A Set of Principles to Interconnect the Solutions of Physical Systems," Journal of Applied Physics, Vol. 24, No. 8, August 1953.

A set of principles and a systematic procedure are presented to establish the exact solutions of very large and complicated physical systems, without solving a large number of simultaneous equations and without finding the inverse of large matrices. The procedure consists of tearing the system apart into smaller component systems. After establishing and solving the equations of the component systems, the component solutions themselves are interconnected to obtain outright, by a set of transformations, the exact solution of the original system. A simple boundary value problem is solved as an example.

Kruszewski, E.T., "Effect of Transverse Shear and Rotary Inertia on the Natural Frequency of a Uniform Beam," NACA TN 1909, July 1949.

A theoretical analysis of the effect of transverse shear and rotary inertia on the natural frequencies of a uniform beam is presented. Frequency equations are derived for the cases of the cantilever beam, and the free-free beam vibrating symmetrically and anti-symmetrically. Numerical results are presented in the form of curves giving the frequencies of the first three modes of the cantilever beam, and the first six modes of the free-free beam.

Landweber, L. and de Macagno, M.C., "Added Mass of Two-Dimensional Forms Oscillating in a Free Surface," Journal of Ship Research, Vol. 1, November 1957.

This paper gives a unified treatment of the added mass for either horizontal or vertical oscillations at high frequency in a free surface. Some of the more obscure, but known results for vertical oscillation are emphasized. The general results for horizontal vibrations presented here are new.

Leibowitz, Ralph C., "A Method for Predicting Slamming Forces on, and Response of a Ship Hull," DTMB Report 1691, September 1963.

This report describes a method for obtaining digital computer solutions for the excitation forces on and transient response of a ship subject to slam when certain basic data are obtained by computation rather than by measurement.

Leibowitz, Ralph C., "Comparison of Theory and Experiment for Slamming of a Dutch Destroyer," DTMB Report 1511, June 1962.

This report presents a theoretical analysis and computation of the slamming forces acting on a ship, based on an experimental knowledge of the ship's motions. In addition, a computation is made of the transient elastic response and associated hull girder stresses of the ship due to the total force exerted by the fluid on the ship. Comparison of theoretical and measured stresses shows good agreement.

Leibowitz, R.C., "Effects of Damping on Modes of Vertical Vibration of Hull of USS THRESHER (SSN 593)," DTMB Report 1384, March 1960.

The normal modes of vertical flexural vibration of the hull and the steady-state damped response were calculated on a digital computer. Results show that the damping causes appreciable phase changes, at resonance, of the vibration response along the beam; furthermore, at the higher modes the frequency of peak response is greater than that of the corresponding normal mode.

Leibowitz, R.C., "Natural Modes and Frequencies of Vertical Vibration of a Beam with an Attached Sprung Mass," DTMB Report 1215, 1958.

A study was made of the vibration characteristics of a beam with an attached sprung mass. The purpose was to explore the possibility of a more adequate representation of a ship hull as a mass-elastic system subject to vibration. Analytical and electrical-analog methods are devised to determine the natural frequencies and mode shapes of a beam-sprung-mass system. These methods are shown to give results that are reasonably accurate.

Leibowitz, R.C., "USS ALBACORE (AGSS 569), Modes of Rudder Vibration," DTMB Report 1540, August 1961.

With the addition of a motor-propeller system to the lower rudder of the ALBACORE the possibility existed that local resonance frequencies of the rudder within the operating speed range of the ship would occur and hence increase the vibratory response of the ship to propeller-blade forces acting on the rudder. Theoretical analysis indicates, however, that the addition of the motor-propeller system to the rudder would not cause excessive vibrations. This conclusion was verified experimentally.

Leibowitz, Ralph C. and Belz, Donald J., "A Procedure for Computing the Hydroelastic Parameters for a Rudder in a Free Stream," DTMB Report 1508, April 1962.

Methods for evaluating the hydroelastic parameters for a rudder moving in a free stream are described. As an example the rudder of the ALBACORE is used. By means of a theory referenced in this report, computations of rudder-hull vibrations (including flutter) can then be made on a digital and/or analog computer.

Leibowitz, Ralph C. and Belz, Donald J., "Comparison of Theory and Experiment for Marine Control-Surface Flutter," DTMB Report 1567, August 1962.

Both the Extended Simplified Flutter Analysis and Modified Theodorsen Flutter Analysis, proposed by McGoldrick and Jewell, are applied to the DTMB Control Surface Flutter Apparatus. Predictions of vibrational stability and instability based on these analyses are compared with stable and unstable vibrations observed in the apparatus for towing speeds in the range of 0 to 20 knots. The Modified Theodorsen Flutter Analysis shows better agreement with experimental data.

Leibowitz, R.C. and Kennard, E.H., "Theory of Freely Vibrating Nonuniform Beams Including Methods of Solution and Application to Ships," DTMB Report 1317, May 1961.

A comprehensive study which reviews and extends previous work, was made of the derivation of equations for digital and electrical-analog solutions of the natural frequencies and mode shapes of a ship's hull idealized as an elastic beam. Effects of bending, shear, rotary inertia, coupled torsion and bending, initial curvature of the elastic axis, applied forces and torques, sprung masses, and other inertias are included. The calculation of the physical parameters from ship plans is described and the accuracy of results is discussed.

Leibowitz, Ralph C. and Standhagen, A.G., "Theory of Static and Dynamic Loads on a Rudder in a Steady Turn," DTMB Report 1647, February 1963.

A rapid approximate procedure is given for predicting the static and dynamic loads on a rudder of a surface ship or submarine in a steady horizontal turn as a function of the rudder angle of attack.

Lewis, F.M., "Dynamic Effects," Chapter 2, Vol. 2 of Marine Engineering, edited by H.L. Seward, published by SNAME, 1944.

This chapter includes a basic treatment of vibration theory, discusses torsional vibrations of reciprocating engine systems and of geared turbine drives, balancing problems, and hull vibration.

Lewis, F.M., "Propeller Vibration," Trans SNAME, Vol. 43, 1935.

As a result of tests on a model of the PRESIDENT HOOVER the vibration generating forces of blade frequency were divided into three types of forces, listed in order of magnitude: bossing forces, hull suction forces, bearing forces. This is reported in this and the 1936 paper of the same name.

Lewis, F.M., "Propeller Vibration," Trans SNAME, Vol. 44, 1936.

As a result of tests on a model of the PRESIDENT HOOVER the vibration generating forces of blade frequency were divided into three types of forces, listed in order of magnitude: bossing forces, hull suction forces, bearing forces. This is reported in this and the 1935 paper of the same name.

Lewis, F.M., "The Inertia of the Water Surrounding a Vibrating Ship," Trans SNAME, Vol. 37, 1929.

The inertia of the water surrounding a vibrating ship is theoretically derived on the basis of the effects of certain geometric shapes moving in a fluid.

Lewis, F.M., "Vibration and Engine Balance in Diesel Ships," Trans SNAME, 1927.

Lewis, F.M., and Auslaender, J., "Virtual Inertia of Propellers," JSR, March 1960.

On the basis of theoretical and experimental results this paper proposes empirical formulas for longitudinal and torsional virtual inertia for vibrating propellers.

Lewis, F.M., and Tachmindji, A.J., "Propeller Forces Exciting Hull Vibration," Trans SNAME, Vol. 62, 1954.

This paper outlines the methods used in measuring the various types of vibratory forces on models and full-scale vessels, and presents experimental results obtained from models which include such effects as rpm, axial and tip propeller clearances, presence of rudder and rudder-propeller clearances.

Little, R.S., "Bibliography on the Longitudinal Strength of Ships and Related Subjects," Technical and Research Bulletin No. 2-3, SNAME, September 1958.

Macagno, E.O. and Landweber, L., "Irrotational Motion of the Liquid Surrounding a Vibrating Ellipsoid of Revolution," Journal of Ship Research, Vol. 2, June 1958.

MacNeal, R.H., "The Solution of Partial Differential Equations by Means of Electrical Networks," Ph.D. Thesis, California Institute of Technology, 1949.

MacNeal, R.H., "Vibrations of Composite Systems," California Institute of Technology, Tech Report 4, Air Research and Development Command, Office of Scientific Research, Contract AF 18(600)-669, Project R-354-30-1, January 1955.

Mathewson, A.W., "Calculation of the Normal Vertical Flexural Modes of Hull Vibration by Digital Process," DTMB Report 706, February 1950.

A method for the calculations of flexural frequencies and normal modes of ship hulls is presented. A comparison of experimental and computed natural frequencies are given for the USS NIAGARA (APA 87).

Mathewson, Alice W., "Calculation of Torsional Critical Speeds of Electrically Driven Propulsion System with Flexibly Mounted Planetary Reduction Gears," DTMB Report 927, June 1955.

A torsional vibration analysis is given for critical frequencies and normal modes of a flexibly mounted twin planetary gear propulsion system. Results of a numerical example are presented.

Mathewson, A.W., "Preparation of Data for Computation of Vertical Flexural Modes of Hull Vibration by Digital Process," DTMB Report 632, September 1949.

A method is described by which the flexural modes of hull vibration can be calculated—while the ship is still in the design stage—by digital computation. Although the method shows promise of applicability to both horizontal and vertical flexural modes, it is presently recommended for preparation of data on vertical modes only.

Mawby, N., "Vibration Tests on LCU 1621, Equipped with a Special Right-Angle Drive Propulsion System," DTMB Report 1634, August 1962.

This report presents the results of torsional and linear vibration tests performed on LCU 1621 which is propelled by two special right-angle drives with a propeller-nozzle combination.

McCann, G.D., "A Study of the Accuracy of Lumped Parameter and Analog Computer Representations of Cantilevered Beams under Conditions of Static Stress and Dynamic Vibrations," California Institute of Technology, Tech Report 3, Air Research and Development Command, Office of Scientific Research, Contract AF 18(600)-669, Project R-354-30-1, April 1955.

McCann, G.D., "Designing Analog Circuits from Test Data," ISA Journal, June 1956.

It is frequently necessary to analyze a mechanical structure where characteristics are described by direct tests, such as influence coefficient or normal mode shake tests. These do not give such structural parameters as effective spring constants directly. However, analogous circuits can be synthesized to represent systems directly from such test data.

McCann, G.D., "Electrical Analogies for Mechanical Structures," ISA, May 1956.

In the "loop" analogy, the terms of the general force equations are voltages, and Kirchhoff's law for the summation of voltages around closed loops simulates Newton's law of force. In most "nodal" analogies, nodal equations for the summation of currents simulate the force equations. In the past these well known analogies have been limited by imperfect circuit elements, and the inability to develop suitable circuit analogies for any but the simpler examples.

McCann, G.D. and MacNeal, R.H., "Beam-Vibration Analysis with the Electric Analog Computer," Journal of Applied Mechanics, Vol. 17, No. 1, March 1950.

McGoldrick, R.T., "A Theorem on Bending Stresses in Rotating Shafts," DTMB Report 947, June 1955.

It is shown that with the exception of the shaft fitted with a two-bladed propeller, the harmonic components of the varying bending stress set up in rotating propeller shafts due to periodic forces or moments acting on the shaft will have the same amplitude regardless of the position of the strain gage on the circumference of the shaft.

McGoldrick, R.T., "A Vibration Manual for Engineers," DTMB Report R-189 (Second Edition) December, 1957.

This manual contains a collection of formulas useful to design engineers in their efforts to minimize trouble from mechanical vibration. The formulas conform with a notation based on the inch-pound-second system of units unless specifically stated otherwise.

McGoldrick, R.T., "Axial Vibration of Propulsion Systems of Battleships of the BB 57 through 60 Class," DTMB Report 547, January 1948.

Experimental data include amplitudes and resonant frequencies of axial vibration of the shafts. The vibration was considered not serious, but turbine couplings showed excessive wear and prompted further investigation.

McGoldrick, R.T., "Axial Vibration of Propulsion Systems of Battleships of the BB 61 through 66 Class," DTMB Report 551, February 1948.

Axial vibration data was taken during sea trials of two ships of this class. The general problem of the axial vibration of shafts on battleships is discussed with a description of the various parameters involved, including the wake variation of each.

McGoldrick, Raymond T., "Calculations for Hull Vibration of the SS GOPHER MARINER and Comparison with Experimental Results," DTMB Report 1022, May 1956.

An extensive vibration study was made on the GOPHER MARINER sponsored by SNAME in an attempt to evaluate present theoretical methods of dealing with the hull vibration problem. The calculations made for this study are presented here in more detail than was permissible in other publications on this subject.

McGoldrick, R.T., "Calculation of Natural Frequencies and Normal Modes of Vibration for a Compound Isolation Mounting System," DTMB Report 1420, July 1960.

The natural frequencies and normal modes of vibration of a compound mounting system are determined. The system consists of an assembly supported by a set of isolation mountings carried by a cradle which is, in turn, supported by another set of isolation mountings attached to the hull of a ship.

McGoldrick, R.T., "Calculation of the Response of a Ship Hull to a Transient Load by Digital Process," DTMB Report 1119, March 1957.

A digital method of finding the response of a beam-like structure with free ends, such as a ship hull, to an arbitrary load normal to its longitudinal axis is presented. The generality of the solution is pointed out as well as the limitations and need for experimental verification of the validity of the method.

McGoldrick, R.T., "Comparison between Theoretically and Experimentally Determined Natural Frequencies and Modes of Vibration of Ships," DTMB Report 906, August 1954.

The results of vibration-generator tests and theoretical calculations of natural frequencies and normal modes of vibration on eight vessels of widely different types are discussed in this progress report. By using correction factors for the various modes based on the accumulated experimental data, more reliable estimates should be possible in the future.

McGoldrick, R.T., "Buoyancy Effect on Natural Frequency of Vertical Modes of Hull Vibration," Journal of Ship Research, July 1957.

This paper develops a formula for the effect on the natural frequencies of vertical modes of hull vibration of a variable buoyancy force due to a ship's heaving.

McGoldrick, R.T., "Determination of Hull Critical Frequencies on the Ore Carrier SS E.J. KULAS by Means of a Vibration Generator," DTMB Report 762, 1951.

This report describes vibration-generator tests made on the KULAS to determine the critical frequencies of the hull under light and loaded conditions and in both deep and shallow water. Calculated critical frequencies are also given.

McGoldrick, R.T., "Rudder-Excited Hull Vibration on USS FORREST SHERMAN (DD 931) - A Problem in Hydroelasticity," Trans SNAME, 1959. Also DTMB Report 1431, June 1960.

The vibration phenomenon encountered on the FORREST SHERMAN was unusual in that the frequency of the 3-noded horizontal vibration remained constant over a considerable range of speed. The cause was found to be the rudders. This paper explores several conceivable explanations, and accounts for it as a sub-critical control-surface flutter condition.

McGoldrick, R.T., "Ship Vibration," DTMB Report 1451, December 1960.

This report presents a general treatment of the subject of ship vibration, including both the structural and hydrodynamic phases, with suggested procedures for dealing with vibration problems in the ship's early design stage.

McGoldrick, R.T. and Curtis, W.F., "Analysis of Vibration in the Propelling Machinery of the Battleships NORTH CAROLINA and WASHINGTON (BB 55 and BB 56)," DTMB Report 318, March 1945.

Sea trials of two of this class brought attention to excessive axial vibration of their shafts. These results were compared with computed values for various mass-elastic approximations of the propulsion system. After considering many solutions, the number of propeller blades were increased which brought the vibration down to an acceptable level.

McGoldrick, R.T., et al., "Recent Developments in the Theory of Ship Vibration," DTMB Report 739, Revised Edition, October 1953.

It is shown in this report that by considering the ship hull as a floating beam having shearing and bending flexibility with a distributed viscous damping proportional to mass, it is possible to derive equations of motion under external forces by the general Rayleigh method which yields a solution in terms of normal modes of motion.

McGoldrick, R.T. and Jewell, D.A., "A Control-Surface Flutter Study in the Field of Naval Architecture," DTMB Report 1222, September 1959.

This study of control-surface flutter was initiated because of serious hull vibration on destroyers of the DD 931 Class, which had been traced to the rudders. A control-surface flutter apparatus was built and tested in the towing basin. Analyses varying in complexity are explored and compared with experimental results.

McGoldrick, R.T. and Russo, V.L., "Hull Vibration Investigation on SS GOPHER MARINER," Trans SNAME, Vol. 63, 1955. Also DTMB Report 1060, July 1956.

Extensive vibration-generator tests were sponsored by SNAME to evaluate the accuracy of the available analytical methods and calculating procedures by comparison of calculated versus measured results.

MacNaught, D.F., "Discussion of Paper, 'Hull Vibration Investigation of SS GOPHER MARINER,' by R.T. McGoldrick and V.L. Russo," Trans SNAME, Vol. 63, 1955.

Miles, John, "Applications and Limitations of Mechanical-Electrical Analogies, New and Old," Journal of Acoust. Soc. Am., Vol. 14, 1943.

The general problem of mechanical-electrical analogies is discussed. The advantages of Firestone's mobility system is demonstrated. The choice of analogy to be used is usually one of convenience, but certain systems intrinsically make only one analogy possible. An analogy in a system with both electromagnetic and electrostatic coupling is fundamentally impossible as the resulting circuit could not satisfy Maxwell's equations.

Mindlin, R.D. and Deresiewicz, "Timoshenko's Shear Coefficient for Flexural Vibration of Beams," ONR Project NR-064-388, Contract Nonr-266-(09), Tech Report 10, June 1955.

Molloy, C.T., "Use of Four-Pole Parameters in Vibration Calculations," Journal of Acoustical Society of America, Vol. 29, No. 7, July 1957.

Linear elastic systems which have a single input point and a single output point can be characterized by a pair of simple linear equations involving forces, velocities, and the four-pole parameters for the system. This paper shows how this concept used many years in electrical engineering can also be used for mechanical vibrations. A few specific problems are given.

Murray, R. Michael, Jr., "Calculated Natural Frequencies, Normal Modes, and Forced Vibrations of USS SKATE (SSN 578)," DTMB Report 1767, August 1963.

Normal mode shapes and natural frequencies of horizontal, vertical, and longitudinal vibration of the hull-propulsion system were calculated on a digital computer. Longitudinal modes were also analyzed on an electric analog. Forced response of vertical and longitudinal vibrations was determined. The effect of changing the thrust bearing foundation stiffness on the longitudinal mode shapes was determined.

Murtha, J.P., "Virtual Mass of Partially Submerged Bodies," Department of Civil Engineering, Carnegie Institute of Technology, 1954.

Neifert, H.R. and Robinson, J.H., "Further Results from the Society's Investigation of Tailshaft Failures," Trans SNAME, 1955.

This paper reports the results of two recent phases of SNAME's continuing investigation of tailshaft failures. As a result of full-scale and model tests, the effectiveness of stress-relief design modifications is evaluated, and the bending stresses in tailshafts under various operating conditions is evaluated.

Noonan, Christopher J. and Cummings, John T., "Vibration-Generator Tests on NS SAVANNAH in Deep Water," DTMB Report 1784, December 1963. (Proprietary to Maritime Administration; distributed only upon their authorization.)

Vibration-generator tests were made on NS SAVANNAH in deep water while the ship was powered by her emergency propulsion system. Resonant frequencies and mode shapes of the hull for vertical, horizontal, and torsional vibration were measured. Experimental and calculated results compare reasonably well. Recommendations for further tests are made.

Noonan, E.F., "Environmental Vibration Testing for Shipboard Equipment," Shock and Vibration Bulletin No. 23, June 1956.

Noonan, E.F., "Vibration Measurements on Ship S6-2 during Builder's Trials," NKF Report 6006, November 1959. (Prepared for SNAME, Hull Structures Committee).

Vibration trials are conducted under various test conditions to determine important factors to be considered in the development of the SNAME Vibrations Code.

Noonan, E.F., "Vibration Measurements on Ship S6-3 during Acceptance Trials," NKF Report 6010, June 1960. (Prepared for SNAME, Hull Structures Committee)

Various vibration test instruments are evaluated for possible adoption in the Vibration Code under development by the SNAME. Simultaneously various operating conditions are studied for their influence on standard operating test procedures.

Noonan, E.F., "Vibration Measurements on Ship S6-4 during Builder's Trials," NKF Report 6304, June 1963. (Prepared for SNAME, Hull Structures Committee)

Vibration measurements are given for a single screw cargo vessel having principal dimensions as follows:

Block Coefficient	0.57	Tonnage Dead Wt.	12,700 tons
Length o.a.	572'-0"	Tonnage Gross	11,310 tons
Length b.p.	541'-0"	Tonnage Net	6,809 tons
Breadth	75'-0"	Max. Disp.	20,110 tons
Depth	42'-6"		
Draft	30'-6"		

Noonan, Edward F. and Zaloumis, Angelos, "Shipboard Vibration and Noise Considerations in the Design of River Towboats," DTMB Report 1758, July 1963.

Many problems of vibration and noise aboard ship are identified, and those which are of particular concern in the design of river towboats are reviewed. The paper is addressed primarily to the naval architect, shipbuilder, or operator and identifies those areas to which attention should be drawn during design and development.

Ormondroyd, J., et al., "Dynamics of a Ship's Structure," Project M670-4, Contract N5ori-116, Engineering Research Institute, University of Michigan, June 1951.

Theory of ship vibration.

Paladino, Anthony R., "Vibration-Generator Tests of Propulsion-System Elements on the USS TIMMERMAN (EAG-152)," DTMB Report 1016, March 1956.

Vibration-generator tests were made on the port reduction gear unit, the starboard planetary gear unit, and the high speed shaft. Additional frequency and amplitude data were obtained for use in a general study of propulsion units.

Paladino, Anthony R., "Vibration-Generator Tests of the Propulsion-System Reduction-Gear Units on the USS FORREST SHERMAN (DD 931)," DTMB Report 1028, April 1956.

Vibration-generator tests were made on the starboard and port reduction gear units with the line shafting uncoupled. The longitudinal spring constants of the foundations are computed to be 2.9×10^6 lb/in. and 1.6×10^6 lb/in. Additional frequency and amplitude data were obtained on these units for use in a general study of propulsion units and their foundations.

Paladino, A.R., "Vibration Survey on USS DECATUR (DD 936)," DTMB Report 1271, March 1960.

A vibration-generator test and underway vibration survey were performed. During the former, measurements were made on the mast, hull, and rudder. Underway, measurements were made of the propulsion system as well. A serious vibration of the ship's rudders was experienced, but corrected by changing the rudder tow-in.

Palmer, F.W., Jr., "Motions of a Converted T-2 Tanker, USS MISSION CAPISTRANO (TAG 162)," DTMB Report 1790, December 1963.

This report presents the results of motions experienced in heavy seas by a T-2 tanker modified by removal of a section of the ship structure to provide a large vertical well. Measurements are analyzed in a statistical manner. Comparison is made with an unmodified T-2 Tanker.

Panagopolos, E.P., "Design-Stage Calculations of Torsional, Axial, and Lateral Vibrations of Marine Shafting," Trans SNAME, Vol. 58, 1950.

The purpose of this paper is to furnish enough information to enable the designer to investigate the torsional, longitudinal, and lateral vibration effects on marine shafting over a wide range of running speeds while the installation is still in the designing stage.

Panagopolos, E.P. and Nickerson, A.M., "Propeller Shaft Stresses under Service Conditions," SNAME, 1954.

Part 1 of this paper is devoted to a review of shaft loading and vibratory behavior contributing to bending stress variations. Part 2 deals with an experimental tailshaft bending stress investigation on the 29,000 ton tanker CHRYSLER.

Pavlenko, G.E., "A Method of Calculating Ships' Vibration Frequencies," Engineering, June 1926.

Pien, P.C. and Ficken, N.L., "The Measurement of Propeller-Induced Vibratory Forces on Scale Ship Models," Paper presented at ATTC Conference, September 1959.

An improved technique of measuring model vibratory forces has been developed, involving elastic isolation of the model stem. This paper is intended to describe the new model test method. Some model results obtained for a series of stem variations based on Series 60 using these techniques are included by way of illustration.

Plumpe, David J., "A Ship Propeller-Shaft Strain-Measuring and Telemetering System," DTMB Report 1714, January 1963.

This report describes a telemeter system for obtaining simultaneous strain data from five gage locations on a ship's rotating propeller shaft.

Pode, Leonard, "The Determination of Frequency Response from Test Results That Are of Short Duration and Not Precisely Periodic," DTMB Report 926, June 1955.

Consideration is given to the problem of determining frequency response from tests of relatively short duration, under conditions in which the periodicity of the input and output functions may be somewhat disturbed by such factors as the presence of a decaying transient or the influence of stochastic variables. A method of analysis is proposed which involves the evaluation of "moving average" Fourier coefficients.

Polachek, H., "Calculation of Transient Excitation of Ship Hulls by Finite Difference Methods," DTMB Report 1120, July 1957.

A system of finite difference equations based on the nonuniform beam theory is presented for use in the calculation of the response of a ship hull to transient forces. The conditions for stability of these equations are derived. The feasibility of the method is tested by the solution of a vibration problem for a specific hull discussed in DTMB Report 1119.

Price, Richard L., "Stern Area Vibration Measurements on USS OBSERVATION ISLAND (EAG 154)," DTMB Report 1595, January 1962.

Vertical, athwartships, and fore-aft vibrations were measured at the stern under calm and rough-water conditions with the ship underway. The principal components of observed vibrations were at propeller blade and double blade frequencies. Experimental and calculated results show good correlation.

Price, Richard L., "The David Taylor Model Basin Two-Component Pallograph," DTMB Report 1730, May 1963.

The pallograph described in this report is a simple seismic device designed and developed at DTMB. The instrument's characteristics and capabilities are mentioned and a complete alignment and operating procedure are given.

Price, Richard L., "The TMB 40,000-Pound, Three-Mass Vibration Generator, Its Description and Operation," DTMB Report 1771, November 1963.

This vibration generator, designed to excite vibrations in large structures, is capable of generating forces of up to 40,000 pounds and moments up to 120,000 ft-lbs over a frequency range from 0.6 to 20 cps. This report describes the mechanical and electrical parts of the generator and the principle of operation.

Price, Richard L., "The TMB 5,000-Pound, Three-Mass Vibration Generator, Its Description and Operation," DTMB Report 1781, December 1963.

This vibration generator, designed to excite vibrations in large structures, can generate forces up to 5,000 lbs and moments up to 8,500 ft-lbs over a frequency range from 0.42 to 33.3 cps. This report describes the mechanical and electrical parts of the system and gives detailed operational instructions.

Price, Richard L., et al., "Bending and Torsional Stresses in Propeller Shaft of USS OBSERVATION ISLAND (EAG 154) in Smooth and Rough Sea," DTMB Report 1596, June 1962.

During 1960, tests were conducted to check the adequacy of the existing propeller shaft of this ship. The bending and torsional stresses obtained for this shaft are evaluated, and bending stresses are compared with results obtained on other vessels. The report includes a harmonic analysis of bending stresses, a comparison of measured values with theoretical bending stresses computed from wake survey data, and suggestions for future work.

Prohl, M.A., "A General Method for Calculating Critical Speeds of Flexible Rotors," Journal of Applied Mechanics, Vol. 12, No. 3, September 1945.

The actual rotor is simulated by a rotor in which the mass is concentrated at several equally spaced stations. The masses are considered to be connected by weightless flexural members.

Reed, F.E. and Bradshaw, R.T., "Ship Hull Vibration, Part II—The Distribution of Exciting Forces Generated by Propellers," CONESCO Report F-101-2, Contract Nobs 77150, June 1960.

This paper presents a practical method of computing the three components of force and the three components of moment on a propeller with the water-inertia effects included.

Ritger, P.D. and Breslin, J.P., "A Theory for the Quasi-Steady and Unsteady Thrust and Torque for a Propeller in a Ship Wake," Experimental Towing Tank, Stevens Institute of Technology, Report 686, July 1958.

Unsteady aerodynamic theory is applied to the problems of varying thrust and torque experienced by a marine propeller working in a non-uniform wake.

Robinson, Donald C., "Calculated Natural Frequencies and Normal Modes of Vibration of the USS OKINAWA (LPH 3)," DTMB Report 1766, August 1963.

Normal mode shapes and natural frequencies of vertical, horizontal, and coupled torsion-horizontal vibration were calculated for the hull. The calculated natural frequencies for a heavy displacement for vertical and horizontal vibration are compared with experimental results.

Robinson, Quentin R., "Measurements of Motion and Thrust Variation on Main Propulsion System of USS FRED T. BERRY (DDE 858)," DTMB Report 887, January 1954.

Measurements of steady thrust, alternating thrust, and vibratory motions of both reduction gear cases were obtained with the ship operating at various shaft speeds.

Robinson, Q.R., "Vibration Machines at the David W. Taylor Model Basin," DTMB Report 821, July 1952.

Several types of vibration machines are used at DTMB for calibrating vibration instruments and for obtaining the vibration characteristics of ships and equipment. In this report these machines are described, some of their characteristics are listed, and brief operating instructions are given.

Russell, W.T., "Lumped Parameter Analogies for Continuous Mechanical Systems," Ph.D. Thesis, California Institute of Technology, 1950.

Russell, W.T., et al., "An Improved Electrical Analogy for the Analysis of Beams in Bending," Journal of Applied Mechanics, September 1953.

Russo, V.L. and McGoldrick, R.T., "Hull Vibration Investigation of SS GOPHER MARINER," SNAME, Vol. 64, 1956. Also DTMB Report 1060, July 1956.

This report describes methods for determining influence coefficients for use with formulas developed at DTMB for computing the critical frequencies of whirling vibration of propeller shafting systems, and tabulates, for purposes of comparison, the computed and experimentally determined natural frequencies.

Ryder, F.L., "Energy Versus Compatibility Analogs in Electrical Simulators of Structures," Journal of Aero/Space Science, February 1959.

Ryder, F.L. and Zaid, M., "Direct Electrical Analogs of Double 6-Degree-of-Freedom System," Scientific Research Staff, Republic Aviation Corp, Farmingdale, New York, Contract Nonr-2952(00) (X), February 1960.

Saunders, H.E., "Hydrodynamics in Ship Design," published by SNAME, 1957.

This is a comprehensive treatment of the subject in two volumes. Subjects covered include fluid flow, ship motion, wave effects, propulsion principles, vibration considerations, and the application of these things in ship design.

Schmitz, M.A. and Simons, A.K., "Man's Response to Low Frequency Vibration," ASME Paper 59-A-200, presented at Annual Meeting, 1959.

Schneider, Joseph, Jr., "Calculated Natural Frequencies, Normal Modes, and Forced Response of the Hull of USS LAFAYETTE (SSB(N) 616)," DTMB Report 1752, August 1963.

Natural frequencies and normal mode shapes of vertical and longitudinal vibration of the hull were calculated. The longitudinal and vertical response to a sinusoidal driving force is also calculated. The main propulsion plant, being resiliently mounted, results in two more vertical natural frequencies than when the machinery is rigidly mounted.

Sidall, J.W., et al., "Approximate Analytical Methods for Determining Natural Modes and Frequencies of Vibration" Department of Aero Engineering, MIT, ONR Contract N5-orl-07833, ONR Project NR-035-259, January 1951.

Stuntz, G.R., et al., "Series 60 - The Effect of Variations in Afterbody Shape upon Resistance, Power, Wake Distribution, and Propeller-Excited Vibratory Forces," SNAME, November 1960.

The effect of change in stem shape, from U to V-form, upon resistance, power, wake distribution, and propeller-excited vibratory forces has been investigated by using a three model series. The three models differ only in the shape of stem sections which range from extreme U to V-shape. The results of resistance, propulsion, wake survey, and vibratory-force tests are presented. These tests with the exception of the wake survey were conducted at design displacement and ballast conditions.

Tachmindji, A.J. and Dickerson, M.C., "The Measurements of Oscillating Pressures in the Vicinity of Propellers," DTMB Report 1130, 1957.

This report presents measured oscillation pressures near a propeller as a function of various parameters.

Tachmindji, A.J. and Dickerson, M.C., "The Measurement of Thrust Fluctuations and Free-Space Oscillating Pressures for a Propeller," DTMB Report 1107, 1957.

This report presents a method of measuring the thrust fluctuation produced by a propeller and the oscillating pressure at a point near a propeller.

Tachmindji, A.J. and McGoldrick, R.T., "Note on Propeller-Excited Hull Vibrations," Journal of Ship Research, Vol. 3, No. 1, June 1959.

This paper presents a summary of the information and techniques which are available to the designer for predicting the levels of service vibration of a ship in the design stage. This involves the two phases of estimating the exciting forces and the vibratory response of a hull to given forces.

Thompson, W.T., "Matrix Solution for Vibration of Nonuniform Beams," Journal of Applied Mechanics, Vol. 17, 1950 or ASME Trans, Vol. 72.

Vane, Francis F., "A Guide for the Selection and Application of Resilient Mountings to Shipboard Equipment," DTMB Report 880, Revised Edition, February 1955.

This manual has been prepared to provide guidance to design agencies for the selection and application of resilient mountings to shipboard equipment. For the more commonly encountered arrangements, the computations have been simplified and systematized as much as possible.

Vane, F.F., "Natural Frequencies of Side Plating, Bulkheads, Decks, and Radar and Radio Supports, Measured Aboard Three Cruisers, Three Destroyers, a Submarine, and a Battleship," DTMB Report 548, April 1948.

Natural frequencies of various local structures were obtained in three ways: with a mechanical vibrograph, from oscillograms of shock motion, and by calculations based on the assumption of several conditions of edge restraint.

Vane, Francis F., "Vibration-Generator Tests of the Propulsion-System Reduction-Gear Unit on the USS DEALEY (DE 1006)," DTMB Report 1038, May 1956.

A vibration-generator test was performed on the reduction-gear unit of the propulsion system with the line shaft uncoupled. The resonant frequency of 660 cpm corresponds with a longitudinal spring constant of the foundation of 1.76×10^6 lb/in. Additional data were obtained for use in a general study of propulsion units and their foundations.

Ward, L.W., "Added Mass of Cylinders Representing Typical Modern Submarine Cross-Sections," Technical Research Group (TRG), Inc., Syosset, L.I., N.Y., Tech Report 1, Contract Nonr-3090(00) (x), October 1960.

The cross sections of typical modern submarines in way of the superstructure and/or sail are idealized to a circular arc "bump" and vertical fin combined with a circular main hull. The resulting flow and added mass for vertical and horizontal vibration are calculated. Specific examples are worked out and conclusions drawn.

Wigle, Bruce M., "Vibration-Generator Tests on the Propeller Shaft of the USS FORRESTAL (CVA 59)," DTMB Report 1007, July 1956.

A vibration-generator test was conducted on an Alloy 4 propeller shaft installed on the FORRESTAL to determine the natural frequencies and modes of lateral vibration. The experimental data are compared with results predicted by theoretical methods.

Wigle, B.M. and Jasper, N.H., "Determination of Influence Coefficients as Applied to Calculations of Critical Whirling Speeds of Propeller-Shaft Systems," DTMB Report 1050, May 1957.

Formulas developed at DTMB for computing the critical frequencies of whirling shafts require influence coefficients in their application. This report describes methods of determining the influence coefficients.

Wilson, W. Ker, "A Review of Ship Vibration Problems," Marine Engineering and Naval Architecture, July, August, October, November 1955. Also published in ASNE Journal May 1954.

Yeh, H.Y., "Thrust and Torque Fluctuations for APA 249, DTMB Model 4414," DTMB Report 1364, January 1960.

A velocity survey was conducted on Model 4414 to obtain data needed to calculate the thrust and torque fluctuations due to nonuniform wake distribution over the propeller disk for the APA 249.

3. MACHINERY REPORTS

Allnutt, R.B., "Vibration Survey of the USS CORAL SEA (CVB 43) Conducted during Ship Trials," DTMB Report C-268, October 1949.

This vibration survey was made to determine the vibration characteristics of the hull and machinery with different propellers and to determine the effect of various bottom paints on the inflow to the propellers and thereby effecting the ship vibration. It was found that four-bladed propellers outboard and five inboard was the best arrangement, and that the effect of different bottom paints was negligible.

Best, S.G., "Propeller Balancing Problems," SAE Journal, November 1954.

Breslin, J.P., "A Theory for the Vibratory Effects Produced by a Propeller on a Large Plate," Journal of Ship Research, Vol. 3, No. 3, December 1959.

The effect on an infinite plane of a single-bladed propeller rotating on a shaft parallel to the plane in a uniform inflow is first considered. The vibratory forces of this system and multiblade systems are discussed for conditions of uniform and nonuniform inflow.

Breslin, J.P. and Tsakonas, S., "Marine Propeller Pressure Field Due to Loading and Thickness Effect," Trans SNAME, Vol. 67, 1959.

This paper presents the blade-frequency pressure field of a propeller as a function of torque and thrust loading, and blade thickness effects. The latter had not been accounted for previously. Theoretical results are compared to experimental results.

Breslin, J.P., "Review and Extension of Theory for Near-Field Propeller Induced Vibratory Effects," Presented at Fourth Symposium on Naval Hydrodynamics, Washington, D. C., August 1962.

A review of the theoretical studies of ship propeller induced pressures and forces on nearby boundaries in the last decade is given with emphasis only on principal results. Simple formulas are developed for the blade frequency vibratory force.

Breslin, J.P., "Ship Vibration, Part I - Propeller-Generated Excitations," Applied Mechanics Review, Vol. 13, No. 7, 1960.

This paper presents the state of knowledge of blade frequency pressure effects and vibratory thrust and torque.

Breslin, J.P. and Tsakonas, S., "The Blade Frequency Velocity Field Near an Operating Marine Propeller Due to Loading and Thickness Effects," Sixth Annual Conference on Fluid Mechanics, University of Texas, 1959.

The velocity fluctuations due to loading and blade thickness effects at any point in the vicinity of a propeller operating in open water conditions in an incompressible ideal fluid are determined. Broad conclusions are drawn as to the relative magnitudes of the contributions of each of the elements to the various velocity components. The blade thickness effect on the pressure and velocity fields is shown to be of primary importance.

Breslin, J.P., "The Pressure Field near a Ship Propeller," Journal of Ship Research, Vol. 1, No. 4, March 1958.

A brief summary is given of efforts in the field of naval architecture on the problem of determining the vibratory forces and moments produced by a ship propeller, and an account of the principal contributions made by aeronautical researchers on the problem of computing the fluctuating pressure field near a propeller. Some characteristics of the pressure field are discussed briefly.

Breslin, J.P., "The Unsteady Pressure Field Near a Ship Propeller and the Nature of the Vibratory Forces Produced on an Adjacent Surface," Stevens Institute of Technology, Experimental Towing Tank Report 609, 1956.

Forces on a flat plate were calculated in a uniform flow when a single-line vortex passed the plate. The calculations were for the two-dimensional problem. Results show that clearances behind the vortex are not as important as clearances ahead of the vortex, or clearances between hull and propeller are more significant than those between propeller and rudder.

Bryant, F.B., "Alternating Bending Stresses in the Shaft of a 110-Foot Submarine Chaser," DTMB Report R-187, March 1944.

In tests aboard a 110-foot subchaser, alternating strains in bending and in thrust of a propeller shaft were measured underway and found to correspond to stresses of 500 psi or less. The apparatus and procedure used are described.

Buchmann, E. and Jasper, N.H., "Vibration Measurements on Port Propulsion System of USNS POINT BARROW (T-AKD 1)," DTMB Report 1286, December 1958.

Vibrations were measured to determine the cause of an engine casualty. Large torque variations of the propeller shaft occurred at very low rpm and generated thrust variations. These vibrations are probably self-excited by large binding forces at the shaft bearings. Vibration resonances at turbine and double-turbine frequencies occurred at the turbine housing at about 140 shaft rpm and are probably excited by unbalance in the turbine system.

Buchmann, E. and Birmingham, J.T., "Vibration Survey on U.S. Army Ship LT COL JOHN U.D. PAGE (BDL-1X)," DTMB Report 1343, July 1959.

A vibration survey was conducted on this ship to ascertain the cause of excessive vibration of bulkheads bounding the aft ballast tanks in the area of the shaft alleys.

Elmer, G.D., "Design Formulas for Yielding Shock Mounts," DTMB Report 1287, January 1959.

Design formulas are given for both the elastic characteristics and the plastic limit loads for three different configurations of yielding shock mounts. In addition, the behavior of these mounts is discussed, and a sample design computation is carried out.

Feldman, S., "Dynamic Balancing for Noise Reduction," Department of Navy, Bureau of Ships R & D Report 371-V-24, April 1955.

Ficken, N.L. and Gawlik, S.G., "Model Flow Studies to Investigate Propeller-Excited Vibrations on U.S. Army Ship LT COL JOHN U.D. PAGE (BDL-1X) Equipped with Vertical-Axis Propellers," DTMB Report 1412, March 1960.

A model of this ship fitted with twin vertical-axis propellers was run in the Circulating Water Channel at DTMB to investigate visually the source of blade-frequency vibrations. The observations indicated that a vortex system exists on the propeller that might be a vibration source.

Fontaine, W.R., "Calculated Natural Frequencies, Normal Modes, and Forced Response of Hull and Propulsion System of USS SKIPJACK (SSN 585)," DTMB Report 1756, August 1963.

Natural frequencies, mode shapes, and the forced response of the hull in its vertical mode and of the hull-propulsion system in its longitudinal mode are calculated.

Fontaine, W.R., "Calculated Natural Frequencies, Normal Modes, and Longitudinal Responses of MST-12 Counter-Rotating Propulsion System and Coupled Hull of USS JACK (SSN 605)," DTMB Report 1655, October 1962.

Normal mode shapes and natural frequencies of vertical flexural vibration of the hull and of longitudinal vibration of the hull-propulsion system were calculated. The forced response and the effect of thrust bearing foundation stiffness are also considered.

Gariboldi, R.J., "Procedure for Torsional Vibration Analysis of Multimass Systems," Department of the Navy, Bureau of Ships R & D Report 371-V-19, December 1953.

This report presents a systematic procedure for the analysis of torsional vibration of multimass systems. It includes a detailed numerical analysis of a diesel propulsion system as an example.

Gold, P.D., et al., "Vibration Engineering—Resume of Applications to Solutions of Marine Operational Problems Encountered by Naval Vessels," Trans SNAME, Vol. 61, 1953.

This paper presents a summary of the methods developed and used by Boston Naval Shipyard to resolve vibration and noise problems encountered during the operation of Naval vessels.

Hardy, V.S. and Jasper, N.H., "Vibration and Noise Tests of Timken Trunnion Roller Bearings on LSM 297," DTMB Report C-149, December 1948.

The vibration and noise characteristics of Timken trunnion bearings and of standard sleeve-type bearings were determined during a test of both installed on the LSM 297. The vibration tests showed the present design of the trunnion bearing to be unsatisfactory, and recommendations for redesign of its rubber mounting are made. Differences in airborne noise from the two types are insignificant.

Harrison, Mark, "Report on Some New Developments in Noise Isolation Problems," DTMB Report 791, April 1953.

Some recent experimental and theoretical results help to explain the actual behavior of isolation mounts. It has been observed that at sonar frequencies they give much less isolation than elementary theory predicts. Also isolation mounts immersed in water give much less isolation than the same mount in air.

Harrison, M., Sykes, A.O. and Martin, M., "Wave Effects in Isolation Mounts," DTMB Report 766, October 1952.

Both theoretical and experimental studies of wave effects in isolation mounts have been made. The well-known "lumped parameter" theory of vibration mounts holds true only when the wavelength of the elastic wave in the mount is large compared to the dimensions of the mount. Standing waves occur, which in certain frequency ranges decrease the vibration isolation properties of the mount by as much as 20 db. The theoretical and experimental treatments are in good agreement, and indicate various methods for improving the vibration isolation properties of the mount.

Hayman, D.F. Jr., "A Method of Evaluating the Hydraulic Vibration Reducer by an Electrical Analog," DTMB Report 1616, June 1962.

This report presents a method for evaluating the parameters of a hydraulic vibration reducer by an electrical mobility analog. The conversion of the hydraulic properties of the vibration reducer into an equivalent mechanical system is detailed in an appendix.

Hord, J.d'H., "Theoretical and Experimental Investigation of the Shaft-Restraining Block," DTMB Report 497, February 1943.

This report describes conditions under which excessive longitudinal vibrations of shafting and of propelling machinery have been encountered in ships, and outlines the development of a shaft-restraining block to inhibit these vibrations. This block is a piston on the line shaft which moves inside a fixed cylinder. The movement is damped by a partially restricted flow of oil. Several models were tested.

Jasper, N.H., "A Design Approach to the Problem of Critical Whirling Speeds of Shaft-Disk Systems," DTMB Report 890, December 1954.

Several methods for computing the natural whirling frequencies of propeller-shaft systems are presented and discussed. Computed and experimentally determined natural frequencies are compared.

Jasper, N.H. and Rupp, L.A., "An Experimental and Theoretical Investigation of Propeller Shaft Failures," Trans SNAME, 1952.

As a result of the high incidence of tail shaft failures the investigation reported here was undertaken. Tests of a tanker and theoretical considerations lead the authors to make specific recommendations in design procedure, operating procedure, and future research.

Jasper, N.H., "A Theoretical and Experimental Study of Propeller-Shaft Failures," DTMB Report 808, August 1953.

This report presents a detailed study of the stresses in the tailshaft of a T2-SE-A2 Tanker of the MISSION type, including an analysis of the causes of tailshaft failures encountered in these ships as well as in Liberty ships and other ships of similar type. Emphasis is placed on the effects of a whirling type of flexural vibration on the stresses and motions of the shaft. One of the principle conclusions is that the shaft failures are due to a lack of endurance strength of the shaft as designed and built, and not due to a serious lack of endurance strength of the shafting material itself.

Jasper, N.H., "A Theoretical Approach to the Problem of Critical Whirling Speeds of Shaft-Disk Systems," DTMB Report 827, December 1954.

In this report a number of theoretical methods are derived for computing the natural frequencies of whirling vibration of shaft-disk systems including the consideration of rotatory inertia, gyroscopic precession, and flexibility of shaft supports, as well as lumped and distributed masses.

Jasper, N.H., "Structural Vibration Problems of Ships—A Study of the DD 692 Class of Destroyers," DTMB Report C-36, February 1950.

An investigation was made to determine the sensitivity of this class to first order unbalanced forces. The long light hull was found to be lacking in torsional and flexural rigidity compared to other ship types. It was recommended that diagonal stiffeners be installed in the hull girder and that the specifications for straightness and balance of shafting be revised.

Jasper, N.H., "Vibration Survey of the USS MIDWAY (CVB 41) Conducted During Ship Trials of July and August 1947," DTMB Report 690, March 1948.

A vibration survey was made to determine the ship's vibration characteristics with three- and four-bladed propellers. Three-bladed propellers were better as far as machinery vibration was concerned and four bladed were better as far as hull vibration was concerned. The vibration of the outboard propulsion units was acceptable under both conditions, so the author recommends three-bladed propellers on the inboard shaft, and four on the outboard shafts.

Kane, J.R., and McGoldrick, R.T., "Longitudinal Vibrations of Marine Propulsion-Shafting Systems," DTMB Report 1088, November 1956.

This paper shows that, by a systematic analysis of the longitudinal mass-elastic system of a propulsion system, it is often possible to adjust the critical frequencies or select the number of blades for the propeller so as to minimize the effects of resonance. Also blade clearance, appendage design, and thrust bearing foundation effects are considered as factors to be considered in design.

Kennard, E.H., "Some Cases of Vibration Forced by Base Motions or by External Forces," DTMB Report 1394, December 1960.

This report gives formulas for the response of selected simple vibratory systems to either forced motions of their supports or to external forces. The systems treated include a sprung mass, a sprung rotor, a cantilever beam, and a general elastic system attached to a rigid base.

Katz, L., "Mathematical Analysis and Digital Computer Solution of Natural Frequencies and Normal Modes of Vibration for a Compound Isolation Mounting System," DTMB Report 1480, January 1961.

The mathematical analysis and solution of the natural frequencies and normal modes of vibration for a compound isolation mounting system by McGoldrick's method are discussed. The system consists of an assembly supported by a set of isolation mountings carried by a cradle which is, in turn, supported by another set of isolation mountings attached to the hull of a ship.

Kinsey, C.H., "Underway Vibration Survey of the Hull and Propulsion System of the USS DEALEY (DE 1006)," DTMB Report 980, August 1955.

Records of vertical and athwartship vibration were obtained at the bow and at the stern, and of fore-and-aft vibration at the thrust bearing and reduction gear housings.

Kinsey, C.H., "Vibration Characteristics of Main Propulsion Unit in USS GUAVINA (AGSS 362)," DTMB Report 1168, October 1957.

Resonant frequencies and amplitudes of vibration of the resiliently mounted bedplate of the main propulsion unit were determined on GUAVINA during vibration-generator tests at dockside, during underway tests, and during vibration-generator tests with the submarine submerged.

Kinsey, C.H., "Vibration-Generator Tests of Main Thrust Bearing Foundations on USS FORRESTAL (CVA 59)," DTMB Report 954, March 1955.

A vibration-generator test was conducted on the starboard main thrust bearings and their foundations aboard the USS FORRESTAL (CVA 59), while the shafting was disconnected on both sides of the thrust bearings, to determine experimentally the lowest resonance frequencies of these systems with the aim of estimating the longitudinal spring constants of the foundations, which were calculated to be 8.2×10^5 lb/in. and 8.9×10^5 lb/in.

Lewis, F.M., and Tachmindi, A.J., "Propeller Forces Exciting Hull Vibration," Trans SNAME, Vol 62, 1954.

This paper outlines the methods used in measuring the various types of vibratory forces on models and full scale vessels, and presents experimental results obtained from models which include such effects as rpm, axial and tip propeller clearances, presence of rudder and rudder-propeller clearances.

Lewis, F.M., "Propeller Testing Tunnel at the Massachusetts Institute of Technology," Trans SNAME, 1939.

This paper describes the construction and characteristics of the MIT propeller testing tunnel and its instruments. The test chamber is 48" in diameter and water can be pumped through it at up to 33 feet per second.

Lewis, F.M., "Propeller Vibration," Trans SNAME, 1935 and 1936.

As a result of tests on a model of the PRESIDENT HOOVER the vibration generating forces of blade frequency were divided into three types of forces, listed in order of magnitude: bossing forces, hull suction forces, bearing forces.

Lewis, F.M., "Propeller-Vibration Forces," Presented at 71st SNAME Meeting, N.Y., 14 November 1963.

The total force exciting vibration in a ship whether vertical, horizontal or a couple, is the vector sum of a number of separate contributions, generated in diverse manners. The paper represents an attempt to estimate the magnitude of these separate contributions.

Lewis, F.M., "Vibration and Engine Balance in Diesel Ships," Trans SNAME, 1927.

Mathewson, A.W., "Calculation of Torsional Critical Speeds of Electrically Driven Propulsion Systems with Flexibly Mounted Planetary Reduction Gears," DTMB Report 927, June 1955.

A torsional vibration analysis is given for critical frequencies and normal modes of a flexibly mounted twin planetary gear propulsion system. Results of a numerical example are presented.

Mawby, N., "Vibration Tests on LCU 1621 Equipped with a Special Right-Angle Drive Propulsion System," DTMB Report 1634, March 1962.

This report presents the results of torsional and linear vibration tests performed on LCU 1621 which is propelled by two special right-angle drives with a propeller-nozzle combination.

McGoldrick, R.T. and Curtis, W.F., "Analysis of Vibration in the Propelling Machinery of the Battleships NORTH CAROLINA and WASHINGTON (BB 55 and BB 56)," DTMB Report 518, March 1945.

Sea trials of two of this class brought attention to excessive axial vibration of their shafts. These results were compared with computed values for various mass-elastic approximations of the propulsion system. After considering many solutions, the number of propeller blades were increased which brought the vibration down to an acceptable level.

McGoldrick, R.T., "A Theorem on Bending Stresses in Rotating Shaft," DTMB Report 947, June 1955.

It is shown that with the exception of the shaft fitted with a two-bladed propeller, the harmonic components of the varying bending stress set up in rotating propeller shafts due to periodic forces or moments acting on the shaft will have the same amplitude regardless of the position of the strain gage on the circumference of the shaft.

McGoldrick, R.T., "Axial Vibration of Propulsion Systems of Battleships of the BB 57 through 60 Class," DTMB Report 547, January 1945.

Experimental data include amplitudes and resonant frequencies of axial vibration of the shafts. The vibration was considered not serious, but turbine couplings showed excessive wear and prompted further investigation.

McGoldrick, R.T., "Axial Vibration of Propulsion Systems of Battleships of the BB 61 through 66 Class," DTMB Report 551, February 1945.

Axial vibration data was taken during sea trials of two ships of this class. The general problem of the axial vibration of shafts on battleships is discussed with a description of the various parameters involved, including the wake variation of each.

McGoldrick, R.T., "Calculation of Natural Frequencies and Modes of Vibration of Resiliently Mounted Equipment by the UNIVAC at David Taylor Model Basin," Department of the Navy, Bureau of Ships Notice 10462, October 1955.

McGoldrick, R.T., "Calculation of Natural Frequencies and Normal Modes of Vibration for a Compound Isolation Mounting System," DTMB Report 1420, July 1960.

The natural frequencies and normal modes of vibration of a compound mounting system are determined. The system consists of an assembly supported by a set of isolation mountings carried by a cradle which is, in turn, supported by another set of isolation mountings attached to the hull of a ship.

"Military Standard - Mechanical Vibrations of Shipboard Equipment," MIL-STD 167 (Ships), 20 December 1954.

This standard establishes the requirements of most naval machinery and equipment as regards both internally excited vibrations and externally imposed vibrations.

Mueller, H.F., "Recent Developments in the Design and Application of the Vertical-Axis Propeller," Trans SNAME Vol 63, May 1955.

The author reviews past history in Germany and recent developments in U.S. A discussion of the hydrodynamic principles, and of the characteristics and merits of various blade motions is presented.

Neifert, H.R. and Robinson, J.H., "Further Results from the Society's Investigation of Tailshaft Failures," Trans SNAME, 1955.

This paper reports the results of two recent phases of SNAME's continuing investigation of tailshaft failures. As a result of full scale and model tests, the effectiveness of stress-relief design modifications is evaluated, and the bending stresses in tailshafts under various operating conditions is evaluated.

Noonan, E.F. and Zaloumis, A., "Shipboard Vibration and Noise Considerations in the Design of River Towboats," DTMB Report 1758, July 1963.

Many problems of vibration and noise aboard ship are identified and those which are of particular concern in the design of river towboats are reviewed. The paper is addressed primarily to the naval architect, shipbuilder, or operator and identifies those areas to which attention should be drawn during design and development.

Paladino, A.R., "Vibration-Generator Tests of Propulsion - System Elements on the USS TIMMERMAN (EAG 152)," DTMB Report 1016, March 1956.

Vibration-generator tests were made on the port reduction gear unit, the starboard planetary gear unit, and the high speed shaft. Additional frequency and amplitude data were obtained for use in a general study of propulsion units.

Paladino, A.R., "Vibration-Generator Tests of the Propulsion System Reduction Gear Units on the USS FORREST SHERMAN (DD 931)," DTMB Report 1028, April 1956.

Vibration-generator tests were made on the starboard and port reduction-gear units with the line shafting uncoupled. The longitudinal spring constants of the foundations are computed to be 2.9×10^6 and 1.6×10^6 . Additional frequency and amplitude data were obtained on these units for use in a general study of propulsion units and their foundations.

Paladino, A.R., "Vibration Survey of USS DECATUR (DD 936)," DTMB Report 1271, March 1960.

A vibration-generator test and underway vibration survey were performed. During the former measurements were made on the mast, hull, and rudder. Underway measurements were made on the propulsion system as well. A serious vibration of the ship's rudders was experienced, but corrected by changing the rudder toe-in.

Panagopoulos, E., "Design Stage Calculations of Torsional, Axial, and Lateral Vibrations of Marine Shafting," Trans SNAME, Vol. 58, 1950.

The purpose of this paper is to furnish enough information to enable the designer to investigate the torsional, longitudinal, and lateral vibration effects on marine shafting over a wide range of running speeds while the installation is still in the designing stage.

Panagopoulos, E.P., and Nickerson, A.M., "Propeller Shaft Stresses Under Service Conditions," Trans SNAME, 1954.

Part I of this paper is devoted to a review of shaft loading and vibratory behavior contributing to bending stress variations. Part 2 deals with an experimental tailshaft bending stress investigation on the 29,000 ton tanker CHRYSLER.

Pien, P.C., and Ficken, N.L., "The Measurement of Propeller Induced Vibratory Forces on Scale Ship Models," Presented at American Towing Tank Conference, September 1959.

Plumpe, D.J., "Ship Propeller Shaft Strain Measuring and Telemetering System," DTMB Report 1714, January 1963.

This report describes a telemeter system for obtaining simultaneous strain data from five gage locations on a ship's rotating propeller shaft.

Price, R.L., Noonan, E.F., and Feldman, S., "Bending and Torsional Stresses in Propeller Shaft of USS OBSERVATION ISLAND (EAG 154) in Smooth and Rough Sea," DTMB Report 1396, June 1962.

During 1960, tests were conducted to check the adequacy of the existing propeller shaft of this ship. The bending and torsional stresses obtained for this shaft are evaluated, and bending stresses are compared with results obtained on other vessels. The report includes a harmonic analysis of bending stresses, a comparison of measured values with theoretical bending stresses computed from wake survey data, and suggestions for future work.

Ritger, P.D., and Breslin, J.P., "A Theory for the Quasi-Steady and Unsteady Thrust and Torque for a Propeller in a Ship Wake," Stevens Institute of Technology, Experimental Towing Tank Report 886, July 1958.

Unsteady aerodynamic theory is applied to the problems of varying thrust and torque experienced by a marine propeller working in a nonuniform wake.

Robin-on, Q.R., "Measurements of Motion and Thrust Variation on Main Propulsion System of USS FRED T. BERRY (DDE 858)," DTMB Report 887, January 1954.

Measurements of steady thrust, alternating thrust, and vibratory motions of both reduction gear cases were obtained with the ship operating at various shaft speeds.

Stutz, G., Pien, P., Hinterhan, W., and Ficken, N., "Series 60 - The Effect of Variations in Afterbody Shape Upon Resistance, Power, Wake Distribution, and Propeller Excited Vibratory Forces," Trans SNAME, Vol. 68, 1960.

The effect of change in stem shape, from U to V form, upon resistance, power, wake distribution, and propeller excited vibratory forces has been investigated by testing three models.

Sykes, A.O., "A Study of Compression Noise Isolation Mounts Constructed from Cylindrical Samples of Various Natural and Synthetic Rubber Materials," DTMB Report 845, October 1953.

Transmissibility data are presented for a number of idealized compression mounts constructed from various types of rubber. These data verified the existence of wave effects in the mounts. In this report an attempt at establishing criteria for choosing mount materials is made.

Sykes, A.O., "The Effects of Machine and Foundation Resilience and of Wave Propagation on the Isolation Provided by Vibration Mounts," DTMB Report 1276, January 1959.

The effects on the transmission of vibration through isolation mounts of machine and foundation resilience, and of wave propagation are investigated. The prediction of the effectiveness of mounts is discussed, and curves are presented for estimating their effectiveness under certain conditions. A number of conclusions are drawn relevant to the problems of mount design and selection.

Sykes, A.O., "The Evaluation of Mounts Isolating Nonrigid Machines from Nonrigid Foundations," DTMB Report 1094, October 1957.

This paper develops a mathematical apparatus from mechanical network theory for estimating the effectiveness of mounts isolating nonrigid machines from nonrigid foundations. It treats the isolation of rigid machines in detail, the isolation of nonrigid machines more briefly.

Sykes, A.O., "The Use of Helical Springs as Noise Isolation Mounts," DTMB Report 818, February 1952.

For numerous applications helical spring mounts offer definite advantages from the mechanical point of view, but they are usually inferior to either rubber shear or compression mounts for noise isolation. This report presents the results of an experimental study of five copper manganese and one steel spring and summarizes the theoretical work which has been completed.

Sykes, A.O., "Vibration Isolation When Machine and Foundation are Resilient and Wave Effects Occur in the Mounts," DTMB Report 1404, September 1960.

The problems of estimating the effectiveness of isolation mounts in reducing vibration are discussed. Curves, data, and formulas are presented for estimating the characteristics and effectiveness of both rubber and helical spring mounts.

Tachmindji, A.J., and McGoldrick, R.T., "Note on Propeller-Excited Hull Vibrations," Journal of Ship Research, Vol. 3, No. 1, June 1959.

This paper presents a summary of the information and techniques which are available to the designer for predicting the levels of service vibration of a ship in the design stage. This involves the two phases of estimating the exciting forces and the vibratory response of a hull to given forces.

Tachmindji, A.J., "The Axial Velocity Field of an Optimum Infinitely Bladed Propeller," DTMB Report 1294, January 1959.

This report gives the axial induced velocity ahead of an infinitely bladed propeller. The propeller is simulated by a close succession of ring vortices whose strength vary along the propeller radius and which extend from the propeller plane to infinity. The results are compared with those obtained for a propeller represented by a uniform sink disk.

Tachmindji, A.J. and Dickerson, M.C., "The Measurement of Oscillation Pressures in the Vicinity of Propellers," DTMB Report 1130, April 1957.

This report presents measured oscillation pressures near a propeller as a function of various parameters.

Tachmindji, A.J. and Dickerson, M.C., "The Measurement of Thrust Fluctuations and Free Space Oscillating Pressures for a Propeller," DTMB Report 1107, January 1957.

This report presents a method of measuring the thrust fluctuation produced by a propeller and the oscillating pressure at a point near a propeller.

Tsakonas, S. and Breslin, J.P., "Longitudinal Blade-Frequency Force Induced by a Propeller on a Prolate Spheroid," Stevens Institute of Technology, Davidson Laboratory Report 853, March 1963.

An expression is developed for the longitudinal component of the vibratory force exerted on a prolate spheroid by the operation of a marine propeller in a space-varying field (wake). Numerical calculations indicate the important role played by propeller clearance and slenderness ratio in the magnitude of the vibratory force.

Tsakonas, S., Breslin, J.P., and Jen, N., "Pressure Field Around a Marine Propeller Operating in a Wake," Journal of Ship Research, Vol. 6, No. 4, April 1963.

This paper reports the effect of nonuniform inflow conditions on the vibratory pressure generated by a marine propeller, as determined by the consideration of two mathematical models.

Tsakonas, S. and Breslin, J.P., "Pressure Field Near Counterrotating Propellers," Stevens Institute of Technology, Davidson Laboratory Report 858, September 1961.

Expressions for the vibratory pressure field produced by an operating counterrotating propeller system are developed in terms of first and second blade harmonics of the individual propellers. Pressure signal can be obtained from the sum of the individual propellers by themselves since mutual interference contributes little to vibratory forces. Two counterrotating propellers are much superior than a single propeller of the same thrust and rpm as far as vibration is concerned.

Tsakonas, S., Breslin, J.P., and Chen, C.Y., "Sound Pressure Field Generated by a Marine Propeller Operating in a Wake," Stevens Institute of Technology, Davidson Laboratory Report 832, February 1961.

This paper deals with the effect of nonuniform inflow on the sound pressure generated by a marine propeller. The inflow is considered in terms of its harmonic components. The effect of non-uniformity far overshadows the uniform flow contribution to the sound pressure at points far from the propeller, whereas in the near field the nonuniformity accounts for 10 to 40 percent of the total pressure signal. The effects of compressibility, directional properties of the field, planform blade shape, and effective radius were also studied.

Vane, F.F., "A Guide for the Selection and Application of Resilient Mountings to Shipboard Equipment, Revised," DTMB Report 850, February 1958.

This manual has been prepared to provide guidance to design agencies for the selection and application of resilient mountings to shipboard equipment. For the more commonly encountered arrangements, the computations have been simplified and systematized as much as possible.

Vane, F.F., "Vibration-Generator Tests of the Propulsion-System Reduction Gear Unit on the USS DEALEY (DE 1006)," DTMB Report 1038, May 1956.

A vibration-generator test was performed on the reduction-gear unit of the propulsion system with the line shaft uncoupled. The resonant frequency of 660 cpm corresponds with a longitudinal spring constant of the foundation of 1.76×10^6 lb/in. Additional data were obtained for use in a general study of propulsion units and their foundations.

Wigle, B.M. and Jasper, N.H., "Determination of Influence Coefficients as Applied to Calculation of Critical Whirling Speeds of Propeller-Shaft Systems," DTMB Report 1050, May 1957.

Formulas developed at DTMB for computing the critical frequencies of whirling shafts require influence coefficients in their application. This report describes methods of determining the influence coefficients.

Wigle, B.M., "Vibration-Generator Tests of the Propeller Shaft of the USS FORRESTAL (CVA 59)," DTMB Report 1007, July 1956.

A vibration-generator test was conducted on an Alloy 4 propeller shaft installed on the FORRESTAL to determine the natural frequencies and modes of lateral vibration. The experimental data are compared with results predicted by theoretical methods.

Yeh, H.Y., "Thrust and Torque Fluctuations for APA 249, DTMB Model 4414," DTMB Report 1364, January 1960.

A velocity survey was conducted on Model 4414 to obtain data needed to calculate the thrust and torque fluctuations due to non-uniform wake distribution over the propeller disk for the APA 249.

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